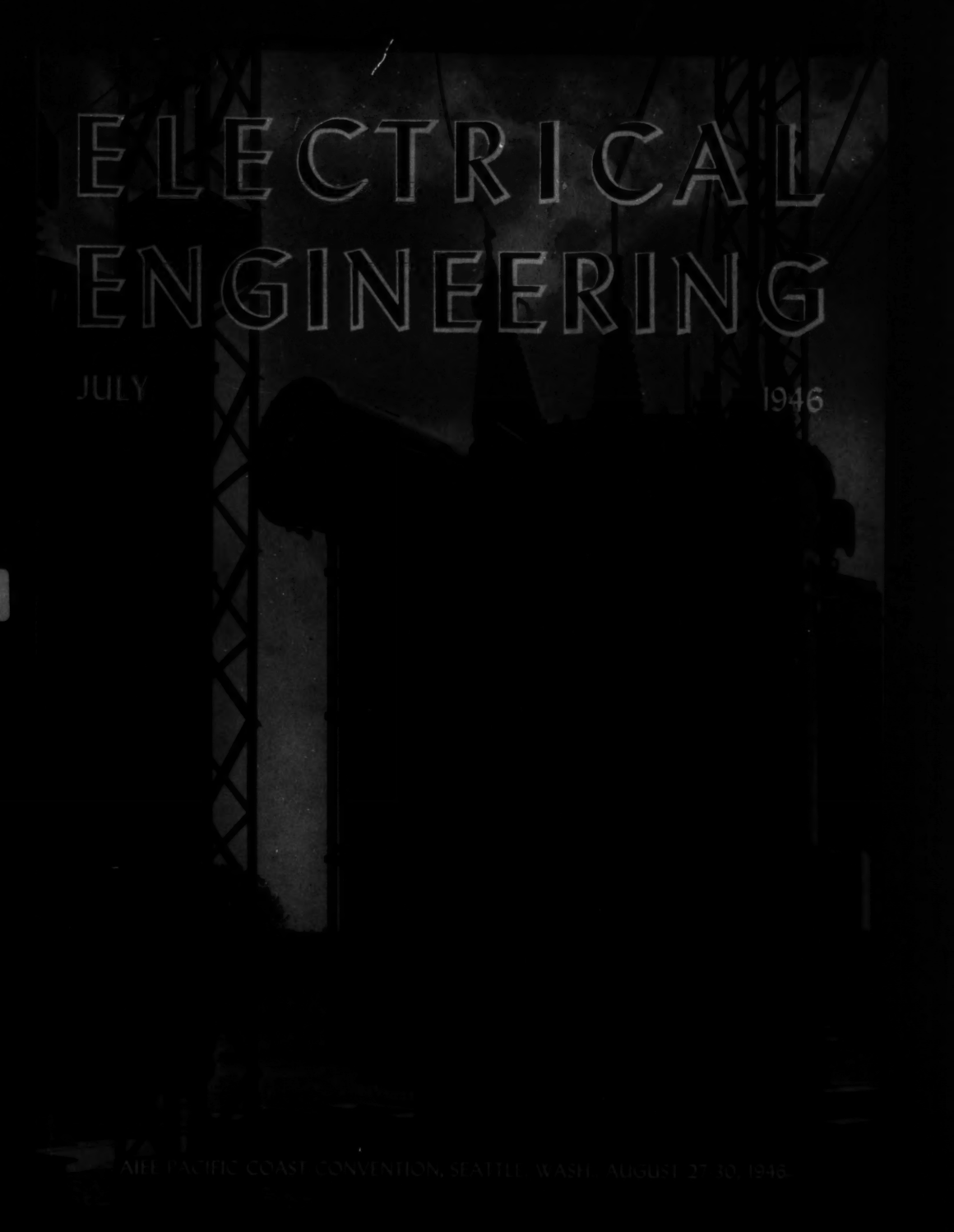
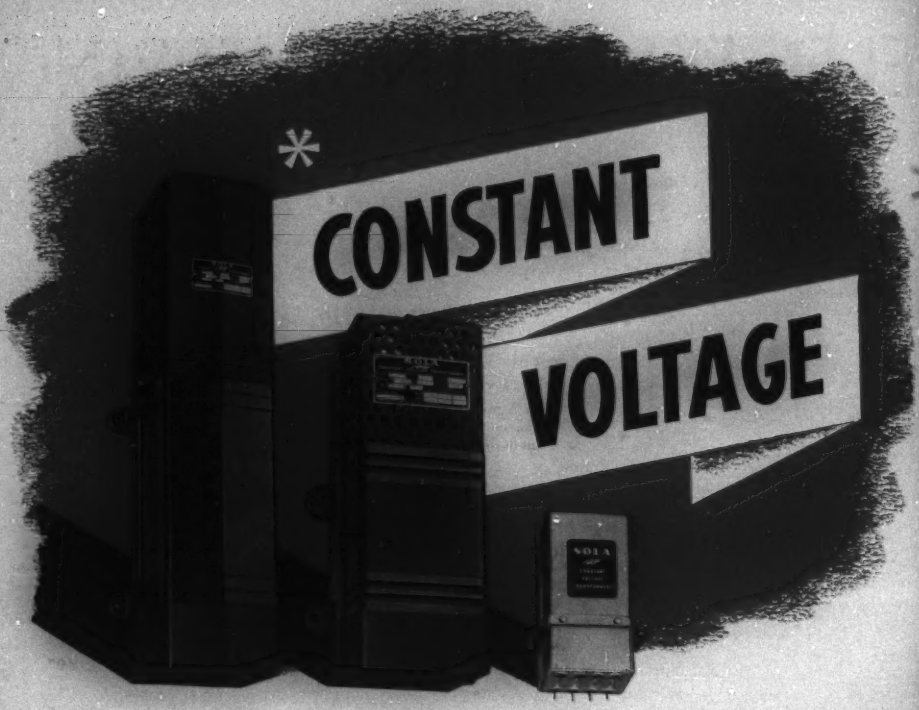
ELECTRICAL ENGINEERING

JULY 1946



AIEE PACIFIC COAST CONVENTION, SEATTLE, WASH., AUGUST 27-30, 1946



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The Cover. A 10,000-kva self-cooled, 13,333-kva forced-oil-cooled 3-winding transformer in a substation of the Puget Sound Power and Light Company in Seattle, Wash., scene of the Pacific Coast convention, August 27–30, 1946. Allis-Chalmers photo

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HIGHLIGHTS.....

Summer Convention. With a registration of 800 for the first day, the summer convention gets under way in Detroit, Mich., as this issue goes to press. Full details of convention activities will appear in the August issue of *Electrical Engineering*.

Pacific Coast Convention. A full postwar program of eight sessions, plus entertainment, sports, and inspection trips, is planned for the Pacific Coast convention which will be held in Seattle, Wash., August 27–30, 1946. In anticipation of the continuing shortage of hotel accommodations, members desiring to attend should make hotel reservations immediately (*pages 329–30*). Complete details of the program will appear in the August issue of *Electrical Engineering*.

Control Council in Germany. The chief weakness of American policy in Germany "is the basic folly of the Potsdam Declaration and the unstable organization with which it is being implemented." This is the conclusion reached by AIEE Past President C. A. Powel who recently spent nine months in Germany as a member of the Allied Control Commission. As an alternative Mr. Powel proposes the adoption of the program devised by the engineering society presidents, a plan which would render Germany helpless to wage war but which would not impair her standard of living (*pages 306–09*).

Engineers and Management. In general the engineer in his relationship as an employee is well trained to handle the engineering aspects of his job and so he finds that his problems are typical employee problems whose solution lies in good management. It is when he becomes part of management himself, with the attendant need for general knowledge and understanding of human relations, that he becomes cognizant of the limitations of the average engineering education and its emphasis on technical training almost to the total exclusion of culture or the social sciences (*pages 322–5*).

V-2 Range Control. Information now is available concerning one of the more formidable enemy weapons, the German V-2 rocket, which has been undergoing tests by the United States Government at Las Cruces, N. Mex. Although no new basic knowledge is employed in the rocket which attained fame during the bombardment of England, the application is felt to be sufficiently novel to be of interest, particularly in the matter of range control (*pages 303–05*).

Employee Training Programs. With the prospect of almost 30 million persons returning to peacetime pursuits in the immediate future, industry is faced with a mass retraining problem as serious as that occasioned by a conversion to wartime production. Perhaps the example set during World War II by the government-financed Engineering Science and Management War Training Program will point the way to its solution (*pages 310–16*).

Wire Recording. Although there has been no widespread commercial exploitation of magnetic wire recording in the United States as yet, experiences with its use by the Armed Forces during World War II indicate a promising market for models adapted for commercial consumption. The simplicity of the recording procedure, the fact that the wire recording can be erased for reuse, and the length of playing time possible with a relatively small record all are factors which should find favor with the consumer in spite of various disadvantages existent in the recording in its present form (*pages 316–21*).

Conservation of Power. Improvements in power supply during the past two decades not only have decreased the unit cost of electricity to the consumer, but have accomplished much in the direction of conservation of fuel and other essential materials. However, in view of today's ever-increasing power requirements, further reduction in total fuel consumption becomes more and more difficult (*pages 326–8*).

Magnet Coils. With the development of silicone insulation, the distinction between insulation standards for magnet coils and those for rotating machines has become more pronounced. Based on this consideration, separate tests carried out on magnet coils reveal that a combination of fiber glass and silicone resin makes an important contribution to improving the thermal life of magnet coil insulation and seem to indicate that the end of the reliable life of such coils is determined by the failure of the silicone resins as bonds (*Transactions pages 412–16*).

Rectifier Installations. Rectifier installations may be classified either as *likely* or as *unlikely* to cause important induction problems, or as indeterminate. A working group of an AIEE subcommittee on electronic power conversion has prepared a report which presents methods by which proposed installations can be placed in one of these categories, thus saving considerable time and effort, either by omitting detailed studies and tests where they are not needed, or by taking the proper precautions when so indicated (*Transactions pages 417–36*).

Double-Reduction Motor. The modern double-reduction traction motor and gear unit incorporates qualities of smallness, compactness, and light weight which make it especially adaptable to a wide range of locomotive sizes where the weight saved in the traction motor may be used in the Diesel engine to provide a more powerful locomotive without increasing the weight. The speed of the double-reduction motor is approximately 67 per cent as much as that of the modern single-reduction motor which makes it unsuitable for heavier high-speed road locomotives (*Transactions pages 471–4*).

Diesel-Electric Drilling Equipment. With the application of the electrohydraulic governor, a war development, to Diesel-electric drilling equipment for the first time, a new degree of protection is attained through prevention of engine overloading. The governor also permits running the engines at the lowest speeds consistent with the desired rig motion and not at full rated speed at all times as in the past (*Transactions pages 447–53*).

Engineering Organizations. The necessity for an over-all engineering society to supplement specialized technical organizations by endeavoring to raise the professional standards of the profession as a whole is stressed in a current letter to the editor. Such a society, the writer believes, may be found in the National Society of Professional Engineers (*page 363*).

Directors' Report. Principal AIEE activities during the fiscal year ending April 30, 1946, are summarized in the 62d annual report of the board of directors. Also included are accountants' statements indicating the financial status of the Institute (*pages 331–50*).

Awards. National and District prize award winners were announced at the AIEE annual meeting in Detroit, June 26 (*page 351*).

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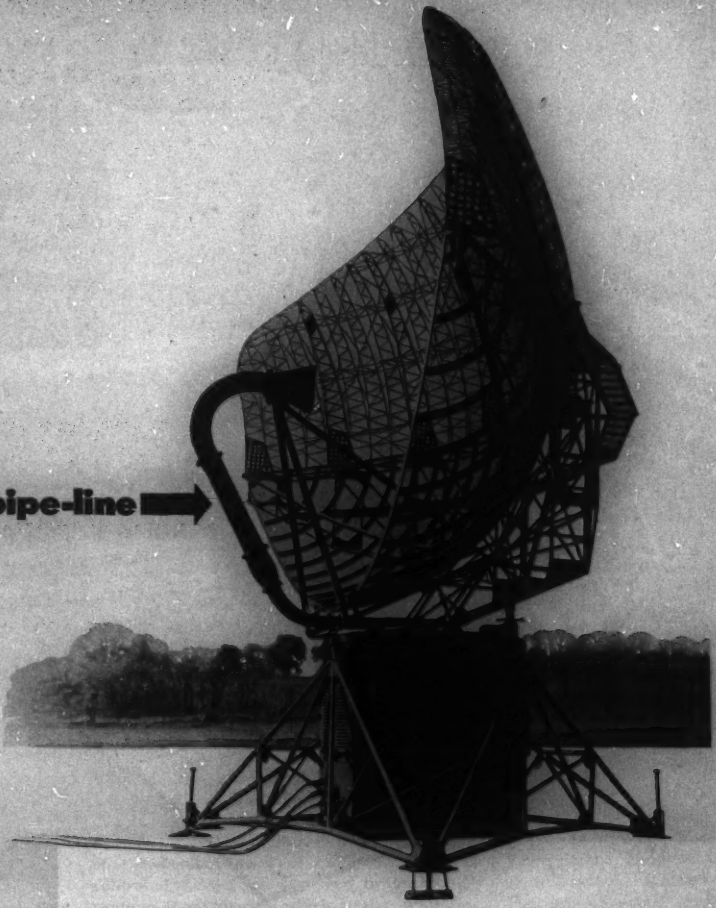

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Now, by the use of special shapes and strategic angles, by putting rods across the inside and varying the diameter, waveguides can be made to separate waves of different lengths. They can slow up waves, hurry them along, reflect them, or send them into space and funnel them back. Bell Laboratories are now developing waveguides to conduct microwave energy in new radio relay systems, capable of carrying hundreds of telephone conversations simultaneously with television and music programs.

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V-2 Range Control Technique

THOMAS M. MOORE

Photo courtesy British Information Service

With the relaxation of military restrictions, information now is available concerning much enemy equipment including the German-developed V-2 rocket which was employed in the bombardment of England. Range control of the V-2 was provided by an integrating accelerometer which, under proper conditions, can be made to give a measure of the velocity at any given instant. By presetting this device and controlling the angle of the missile with respect to zenith, reasonably accurate guidance can be accomplished.

AFTER SOME 20 years of research and development, the Germans successfully launched the first V-2 on Chiswick, England, on September 3, 1944. Although the accuracy of this missile for hitting a pinpoint target could not be depended upon, yet for area bombing it could be expected to land within the area covered by a city.

Before going into a discussion of the means for range control, it is desirable to review briefly the general geometry and launching procedure for this vehicle. At the nose of the missile is the warhead containing the explosive. Behind this is a control compartment which houses means for directing the flight path. Next are two large tanks in tandem containing the alcohol and oxygen. These feed into a combustion chamber and Venturi tube and, when ignited, propel the missile. Two sets of control vanes are located at the rear. One set operates inside the jet stream; the other is located on the trailing edges of four large fins and also is used for flight stabilization.

Upon arrival at the launching site the missile is erected to a vertical position. After the fuel tanks have been filled and the various controls set, the rocket motor is started electrically from a safe distance by means of a cable to the control compartment. The cable is detached at take-off which leaves the rocket to be controlled in flight by its internal mechanism. The rocket starts by climbing vertically and, after reaching a pre-

Thomas M. Moore is associated with the United States Naval Research Laboratory, Washington, D. C.

determined altitude, is tilted toward the target to a final angle of approximately 45 degrees. This tilting is accomplished by means of a gyroscope-controlled program selector.

Control of range of the rocket is obtained by cutting off the supply of rocket fuel when the rocket has reached a velocity sufficient to carry it to the target. Means for controlling the velocity reportedly necessitated considerable effort on the part of the Germans. They first employed radio Doppler apparatus for this purpose but the system was discarded because of its greater complexity. Later they used two integrating accelerometers.

USE OF THE MECHANICAL INTEGRATING ACCELEROMETER

Many of the missiles launched against England were provided with the mechanically integrating accelerometer shown in Figure 1. The enclosed gyroscope is mounted in such a way as to precess at a rate determined by the acceleration of gravity for test purposes before take-off and at a rate determined by the combined forces

Figure 1. Mechanical integrating accelerometer

1. *Gyroscope*
2. *Preset vernier*
3. *Antifriction motor*
4. *Contact arm*
5. *Slip rings*

of gravity and acceleration of the missile after take-off. From the mechanics of a rate gyroscope we may obtain the following:

$$\frac{d\theta}{dt} = \frac{K dv}{dt}$$

Integrating

$$\theta = Kv$$

where

v = velocity of the rocket
t = time
θ = angle through which gyroscope precesses
K = constant

An integration of the acceleration then gives a measure of the velocity where K is a convenient stepdown ratio

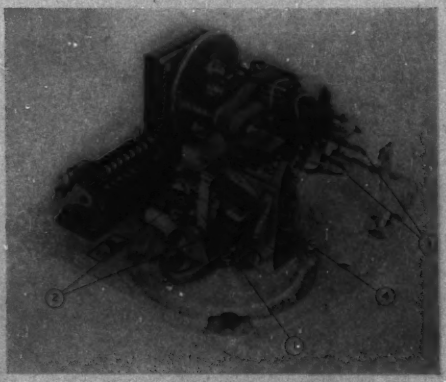

Figure 2. Electrolytic integrating accelerometer

1. *Arm and copper slug*
2. *Electromagnets*
3. *Electroplating cells*

provided by the gear train. Signal for cutoff of the rocket fuel is obtained by means of a cam which actuates a relay when the gyroscope has precessed a predetermined amount. Adjustment of the preset vernier shown in Figure 1 permits setting of the cam to control the fuel cutoff point. The exact setting required is determined from charts which allow for empirical data obtained by test and for a correction for the vertical component of the acceleration of gravity for various tilt angles of the missile while in flight.

As in the afore-mentioned mechanism, if a gyroscope is allowed to precess, the unsupported end gradually will fall as a result of bearing friction so that the precession rate gradually is lessened. In order to offset this error a small 3-phase motor is arranged to drive the gyroscope about its precession axis in order to maintain the contact arm within small limits. This motor, therefore, supplies enough energy to provide an effective frictionless bearing. Direction of the motor is changed by reversing two of the field leads depending on whether

contact is being made in the upper or in the lower position.

USE OF THE ELECTROLYTIC INTEGRATING ACCELEROMETER

Although the aforementioned unit was made with care, a second type of integrating accelerometer proved to be more accurate. This was the electrolytic accelerometer

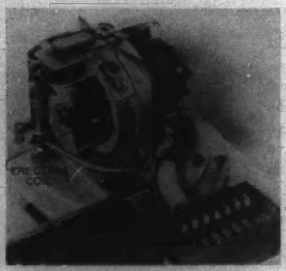

Figure 3. Erecting coil and permanent magnet

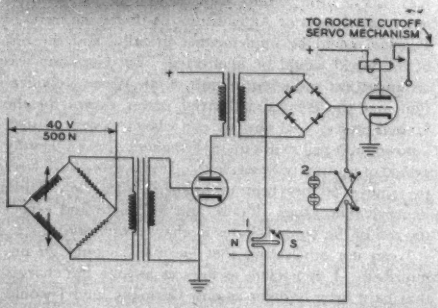

Figure 4. Schematic diagram of electrolytic integrating accelerometer

1. Erecting coil *2. Electrolytic cell*

shown in Figure 2 which was developed under the direction of Doctor Buchold.

In the electrolytic accelerometer an arm is fitted with a copper slug which, when moved within the poles of electromagnets, unbalances a bridge circuit. The signal thus obtained is amplified, rectified, and put through an erecting coil in a permanent magnet field. The coil and magnet assembly are shown in Figure 3. In series with this coil are two electroplating cells (Figure 2) so that the current flowing through the coil and cell units causes a quantity of metal to be transferred within each cell at a rate determined by the acceleration.

Figure 4 shows the circuit external to the components in Figure 3, and is a simulated one set up at the Naval Research Laboratory. For an acceleration of one *g*, the current was found to be two milliamperes at 0.1 volt. The plating cells consist of two silver-wire electrodes of approximately 0.100-inch diameter in a solution of sodium chloride. One of the electrodes in each cell previously has been coated with silver chloride.

By plating a predetermined period of time with the one *g* acceleration available at any launching site a quantity of silver chloride may be deposited on the anodes of the cells. This is removed during the power-on portion of flight at a rate determined by the acceleration of the missile plus gravity.

When all of the silver chloride has been removed from one electrode a signal is obtained as a result of the cell acting as a battery. Metallic silver is formed at the cathode and silver chloride is formed at the anode which causes a voltage to be generated. This force of approximately one volt is amplified and used as a signal to actuate the rocket cutoff relay. This process can be reversed, of course, as many times as desired for test purposes.

Figure 5 shows a recording voltmeter chart of the electrolytic integrating accelerometer during the process of:

(*a*). Plating silver chloride on the unplated electrode.

(*b*). Removing the silver chloride plating.

(*c*). The voltage rise obtained when all of the silver chloride has been removed.

The data shown are for an acceleration of one *g*.

TEMPERATURE REGULATION

Temperature regulation for the cells is provided by a thermostat which controls wire heater elements wound around the glass containers as shown in Figure 4. Power for either accelerometer is furnished by a battery-driven

A—Plate silver chloride
B—Deplate silver chloride
C—Voltage rise (signal)

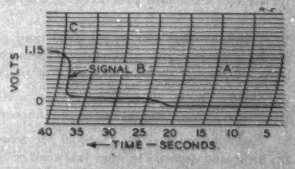

Figure 5. Voltage rise obtained from electroplating cells

motor–generator set requiring 28 volts direct current for the motor and providing a generator output of 42½ volts at a measured frequency of 501 cycles per second (rated 500 cycles per second). The speed of the motor is controlled by a centrifugal governor so that the generator output frequency is held within limits of about two per cent down to 20 volts input to the motor.

Experiences With the Control Council in Germany

C. A. POWEL
FELLOW AIEE

Significant and controversial are these bold and frank comments of an AIEE past president, based on first-hand observation and study over a period of some nine months since the military collapse of Germany. Here is food for serious thought and a challenge to American policy and security. Comments and opinions on the subject are invited.

YOU HAVE BEEN told time and again that we are bungling the job in Germany, that we have no foreign policy, and that we are headed for World War III or for the rocks. It would seem that such a unanimity of opinion must have some foundation in fact. After living for some nine months in daily contact with the problem, I have come to the conclusion that the cause of our troubles is not so much quadripartite disagreements, denazification, fraternization, and other surface manifestations we read about, as it is the basic folly of the Potsdam Declaration and the unstable organization with which it is being implemented. The best management in the world could not run an organization efficiently with a complete turnover of personnel every three or four months, particularly when the task given it is so full of contradictions as the Potsdam document.

The Potsdam Declaration has a dozen or so clauses, which when read over casually sound as innocent and reasonable as the Atlantic Charter, but when analyzed take on an entirely different aspect. In very general terms the Potsdam Declaration stipulates that:

1. Germany shall not be enslaved, and the Germans shall be given an opportunity to re-educate themselves along democratic lines. Germany shall be treated as a single economic entity.

2. Nazism must be eradicated, completely and active Nazis must be removed from positions of influence.

3. Germany must be deprived of her power to make war, and her industrial capacity to wage war must be removed or controlled.

4. Germany will be left enough productive capacity to meet the needs of the occupying forces and displaced persons in Germany and to provide a standard of living not exceeding the average of those of surrounding European countries.

5. Germany will be permitted to produce enough food and light industry to subsist without external assistance according to the permitted standard of living, and to export enough to pay for essential imports.

6. Germany must furnish reparations in the form of industrial capital equipment to the countries against which she waged aggressive war. In addition to the reparations to be taken by Russia from her own zone, she will obtain 25 per cent of the surplus capital equipment in the Western zones.

These terms seem very moderate when one considers the enormity of the German crimes, and if Germany had had as little contact with the rest of the world as, let us say, Russia or Afghanistan, no doubt the terms of Potsdam could be implemented literally, and the rest of the world would be unaffected. But Germany was an important and essential unit of our Western civilization and the greatest industrial power except for the United States; and how we can expect to destroy such a power and still maintain a permanent or even lengthy period of prosperity is not clear. It is as though we were to remove 60 per cent of industry from New York, Pennsylvania, Ohio, Illinois, and Michigan and expect the rest of the United States to enjoy prosperity.

I am not advocating that Germany should go unpunished. I appreciate as fully as anyone the charges that have been brought against Germany, and I would be the last to claim that they are unfounded, or that we need have no fear of another Bismarck or Hitler. The Germans for generations have been used to implicit obedience to a higher authority, and this trait in their characters will not change overnight. They never have known freedom of speech or freedom of action as we understand it. When I was at school in Switzerland, I became by chance quite intimate with one of Germany's great historians, Carl Bleibtren, a very brilliant man. He had been kicked out of Germany for daring to question whether Germany was really a democracy. And that, gentlemen, was in the opening years of this century—long before the first World War.

REPARATIONS AFTER WORLD WAR I

I also appreciate that after the first World War we all were fooled by the Germans, and that our attempt to collect reparations helped them. Britain took the German Merchant Marine to replace her ships sunk by submarines. She got old ships, while the Germans got

Full text of a luncheon talk at the AIEE Southern District meeting, Asheville, N. C., May 14, 1946.

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new, better, and faster ships built with American money. France took coal which she formerly bought from England and so upset her trade balance with that country. Germany got nice new factories also built with money borrowed from the United States. In fact, what little reparations Germany paid were paid with American money, but even so she put up such a hard-luck story that we all called it quits. The German Republic under Friederich Ebert was admittedly a farce fully controlled by the same old war lords, who lost no time planning for the next war.

All this is historical fact, and we would be foolish indeed to ignore it. Germany must be disarmed and her war potentiality completely eliminated, but this end can be achieved without going to all the complications and extreme lengths stipulated by Potsdam, and wrecking the economy of Europe for years to come. I still stand behind the suggestion made in 1944 by the presidents of the five leading engineering societies, of whom I was one.[1] This program would have deprived Germany completely of her power to make war, but she could have gone ahead and rebuilt her peacetime industries and helped lift the countries around her out of the present confusion. Potsdam makes this impossible.

GERMAN POSITION IN EUROPEAN ECONOMY

For the past 40 years, all advanced thought has been on the side of improving the standard of living of all peoples—for idealistic reasons on the part of some, for selfish reasons on the part of others. Prosperity grows in a geometric progression; conversely a depression anywhere soon spreads in ever widening circles to involve the whole industrial world. Any scheme, therefore, that starts out by "reducing the standard of living" of some 70 million people is not based on very intelligent thinking. The war has not changed the geography of Europe. The distribution of its natural resources, arable land, and population remain essentially unaltered, and, no matter what political structure is given to that part known as Germany, it cannot be treated as an independent and unrelated part of European economy. Reducing the standard of living of the Germans is bound to reduce the standard of living of the Poles, Rumanians, Austrians, Hungarians, Czechs, and others who are inextricably linked economically with Germany. Before I left Berlin, we already were being deluged with requests from all over Europe for repair parts for machinery and automobiles built in Germany. If a Pole cannot operate a machine for lack of a part which a German cannot provide, because his factory has been turned in on reparations, I don't know who is the loser, the Pole or the German—certainly we are not adding to the Pole's prosperity or raising anybody's standard of living.

A large part of Germany's industrial structure has been wrecked, but there still remains in Germany a foundation of highways, railways, power systems, communication systems, industrial establishments, and a supply of skilled labor unsurpassed anywhere, and so superior to that of the surrounding countries, that there appears to be no grounds for assuming that manufacturing plants removed under reparations from Germany to surrounding countries can in any foreseeable future play their former role in European economy. Indeed, from what we observed of the removal of German plants by the Russians, it is questionable if the equipment will be fit to put up anywhere.

It probably is not realized generally that this reduction of the standard of living of the Germans to the average of Europe is no minor operation. For instance, steel producing capacity will be cut from a war peak of 28 million tons annually to 7.5 million tons; machine tool producing capacity will be 11 per cent of prewar value; heavy electric equipment and heavy engineering generally will be 30 per cent of prewar value; and so on. Even when war damage is taken into account, there still will be much plant and equipment to be made available for reparations.

POTSDAM'S CONFLICTING CLAUSES

The Potsdam agreement says that Germany is to be allowed enough resources to be self-supporting and sufficient exports to pay for essential imports. Originally it was the intention that Germany also should pay for the costs of occupation. This, too, sounds reasonable. Certainly there seems to be no good reason why the American taxpayer should pay for whatever army and military government is necessary as a result of crimes perpetrated on the world by Germans. But, unfortunately, the answer is not that simple. It was soon evident that, if Germany was to pay for imports and for the army of occupation, exports would have to be of the same order as during her best years, and any idea of reducing her industrial capacity was out of the question. As it is, she probably is going to find it difficult to export enough to pay for essential imports. We still are tearing down in order to meet this "average standard of living" clause. We are rebuilding nothing. Even without this complication, the German export situation would not be particularly happy. Under the Nazis, exports were stimulated artificially by subsidies. It still remains to be seen what business they can obtain in a free competitive market.

The primary objective of the war was to put an end to German aggression, to prevent her periodic attacks on her neighbors. Our armies did a magnificent job of reducing her to the point where she would listen to reason, but, unfortunately, when they were through, "reason" was not forthcoming. In its place came an outmoded revenge philosophy, which in due course will disgust all decent people and will result in total withdrawal from Germany, which then will be free to resume its old policies.

INDUSTRY CURTAILMENT BY ENGINEERS' PLAN

I have no way of knowing who is primarily responsible for Potsdam, but in his book "Germany Is Our Problem," Henry Morgenthau seems to take most of the credit for it. The proper course already had been suggested in the document submitted by the presidents of the engineering societies.[1] Germany could have been rendered helpless to wage war by:

1. Elimination of all factories manufacturing war equipment solely (shell loading plants and the like).
2. Elimination of plants manufacturing aircraft and aircraft parts and control of imports.
3. Elimination of plants manufacturing primary aluminum and magnesium and control of imports.
4. Elimination of all synthetic oil capacity and control of imports.
5. Elimination of 75 per cent of Germany's synthetic nitrogen plant capacity and control of imports.
6. Elimination of 50 per cent of Germany's steel making capacity with particular emphasis on heavy forgings and high alloy steels.

An analysis of this program will show that, while it makes the waging of war impossible, it does not necessarily reduce the German standard of living. An aircraft industry depending only on peacetime requirements cannot be self-sustaining. The total German requirements would be less than 100 planes a year. There is no bauxite in Germany and, therefore, no justification for an aluminum producing industry. They can import aluminum ingots, more profitably and such imports can be controlled. Their steel manufacturing capacity was very much overexpanded, and their production costs were high compared to United States and British costs. Elimination of the old inefficient mills would have helped their cost position.

The implementation of such a program would have been simple, whereas the complications resulting from the Potsdam formula are quite formidable. I have sat in meetings of the four occupying powers in which we have discussed for hours whether the Germans should be permitted to build 20,000 machine tools or 30,000 machine tools a year; 35,000 tractors or 40,000 tractors. All this was made necessary by this arbitrary "standard of living" required by the Potsdam agreement. It took a corps of experts six months to determine what constituted a "standard of living," and when they were through, it was still just an opinion.

The excess capital equipment left over after determination of what the Germans are permitted to keep to satisfy this "average standard of living" is to be turned over to the allied nations in the form of reparations. One would suppose that the Allies had learned after the last war that reparations are a snare and a delusion. "Lend-lease" was "lend-lease" only because we recognized the futility of trying to collect international debts. But at Potsdam we still talked of reparations.

The Germans are a highly intelligent, industrious, and practical people. They have the peculiar characteristic of making work an end in itself. What they produce seems to be a secondary consideration, so long as they are producing something. One would suppose that the intelligent thing to do would be to take advantage of this characteristic and make them produce more and more for the benefit of the surrounding devastated countries. Instead of this we are taking away from them what plant is left from the bombing and general destruction and putting all kinds of hindrances to their efforts at working. This hardly seems to be a policy leading to permanent peace.

RUSSIA'S NON-CO-OPERATION

The Russians have invited large numbers of German experts and scientists to Russia. This is very nice for Russia, but not very useful to the other devastated countries, nor is it calculated to raise the standard of living of Europe. If anyone has any idea that co-operation can be expected from Russia, I don't know on what it is based. There was no evidence of co-operation in Germany. The Potsdam agreement among other things requires that "Germany shall be treated as a single economic unit." Never has a clause in any document been ignored so completely. The fact is we do not have the least idea what Russia is doing or intends to do east of the Elbe, except for what she wants us to know, which is remarkably little. Visits into the Russian zone are prohibited, and censorship of news is complete. We do know, however, that Russia is working assiduously at introducing communism (that is, state monopoly of every activity) throughout the whole district. The Allgemeine Elektrizitäts Gesellschaft plants, for instance, that are in the Russian zone in Germany have been turned over to "public trustees," whereas the plants in the other zones still are under private ownership. The Russians also have confiscated land in their zone from the rightful owners and turned it over to the so-called peasants. This they call "land reform." This is, of course, one of the main planks in the communist doctrine.

As you will have gathered from my remarks, the Potsdam agreement, in my opinion, is not helpful toward solving the world's troubles, but Potsdam is not a peace treaty and was not intended to be permanent. In course of time a peace treaty will be evolved, which must not be permitted to perpetuate the stupidities of Potsdam. This is my only excuse for speaking.

PEACE TREATIES CAN REMEDY SITUATION

In the final treaty there must be a return to those principles on which our Christian religion is based. Oriental revenge may be sweet, but history shows that it never helped the practitioners on any long-term basis. Punishment of the individuals responsible for bringing on the catastrophe and those involved in atrocities certainly is called for, but going beyond this is wrong

from both a moral and a practical point of view, even though Germany as a nation certainly was solidly behind Hitler.

We also should cease pretending that Russia is our ally. Our dealings with her have been and still are entirely one-sided, and there is not the least indication that she intends to change that policy. Russia is interested in Russia and in nothing else. Co-operation and compromise are words that do not exist in the Russian dictionary. We permit the Russians to see anything they wish in our country, but we know nothing of what goes on in Russia. In Berlin we found them better informed on the machine tool industry in the United States than we were ourselves.

For some reason never satisfactorily explained, Russia was permitted to take much more of Germany than she really conquered. American troops could have been in Berlin long before the Russians if so permitted, and with much less bloodshed, because the Germans resisted the Russians but would have surrendered without fighting to the Americans. In all that part of Europe overrun by the Russians, including the Russian zone in Germany, we know little of what is going on, and what little we know does not make pleasant reading. All the evidence points to the fact that they are setting up communist governments responsive to Moscow only. It is difficult to believe that in any free election, the Poles, Czechs, and others would vote for government monopoly of the Russian type with all producers at the mercy of a single master and without the least vestige of liberty of speech, liberty of movement, liberty of ownership. The past history of those countries shows no indication that that was what they wanted. Hitler offered them more or less the same thing, and their reaction was rather violent, as I remember it. But the Russians are past masters at setting up left-wing movements in other countries, and then sitting back to await results. Ordinary common sense would seem to tell us that, if the Russian system is as good as they would have us believe, there would be no need to hide it behind what someone has called an "iron curtain."

GERMANY MUST BE ENTITY

This brings me to the next point. Germany must be treated as a single economic entity. Even Potsdam recognized this, but nothing is being done about it. The Russian zone is the bread basket of Germany and must be made available to all of Germany. Until this is done we shall continue to feed the people in the Western zones as they are certainly incapable of feeding themselves for the time being.

We also must cease pretending we can finance the whole world. Everywhere one encounters the idea that Uncle Sam can provide all necessary food and clothing for everybody; that the wealth of America is unlimited. This squandering of borrowed money eventually must bankrupt private industry and the government itself. Another feature of this lending that will lead inevitably to the death of free enterprise is that the loans are made not by private banks to private banks, but by our government to other governments, which thus are forced to own or closely supervise any enterprise for which the money is used. Moreover, since they need all the dollar exchange to pay interest on this government loan, private undertakings, even if profitable, have no way of getting the money out of the country.

There are advocates who would split up Germany into two, three, or four separate states. This appears to me to be a distinct step backwards—and an unnecessary step. With the scheme suggested in the engineers' proposal and a firm determination to institute a friendly but firm control over Germany for some 25 or 30 years, she can become a useful and valuable contributor to the general improvement of the standard of living of all central Europe—assuming that free enterprise can be saved from the Russian menace. And that will go further toward permanent peace than any scheme based on restriction of production, which after all is the only source of wealth.

REFERENCE

1. Retain Germany's Peacetime Industry. *Electrical Engineering*, volume 63, November 1944, pages 393–4.

Westinghouse photo

Standing 37 feet high when completed, three single-phase transformers such as this one manufactured by the Westinghouse Electric Corporation will step up potential to as much as a half million volts for the high voltage test lines of the American Gas and Electric Service Corporation

Training in Electrical Industries

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The problem of retraining large numbers of war workers for peacetime pursuits confronts many industries today. During the war when industry was faced with the reverse problem, conversion to wartime production, the Federal Government provided aid through the Engineering Science and Management War Training Program under which war plant employees might take advantage of short technical courses offered by co-operating educational institutions throughout the United States. In the hope that industries reconverting to peacetime production might profit through similar methods, this article offers a survey of the University of California's experience with the war training program.

PREDICTIONS have been made that 30,000,000 persons are to change jobs in this readjustment period immediately following the war, in the mass shift from wartime to peacetime occupations. Whatever the number, it is obvious that private industry is faced with a problem in the mass retraining of war workers for peacetime uses as serious and as urgent as that which faced the war industries in training the thousands of workers needed at all levels of skills to man the nation's war plants.

To help the war industries meet this problem, more than 200 educational institutions throughout the United States gave special college-level courses under the Engineering Science and Management War Training Program, developed and financed by the Federal Government through the United States Office of Education. The University of California, because of its location in the nation's ranking war production area, became the largest participant in this program, enrolling more than 150,000 men and women in 4,400 courses, under the direction of Professor Morrough P. O'Brien, dean of the college of engineering at Berkeley.* The university thus gained experience which, in the light of industry's present training needs, may afford many practical suggestions to those confronted with this problem.

Approximately ten per cent of the 151,202 enrollees in war training classes were in electricity or in courses closely associated with electrical engineering. From the beginning of the electrical program, early in 1941, to its termination in June 1945, 16 full-time or part-time supervisors participated in its organization and supervision. Supervision increased with the growth of the program until the equivalent of about 4½ full-time men was required for the peak years 1943–45. Electrical classes were organized on a state-wide basis with the greatest number being conducted in the San Francisco and Long Beach–San Pedro areas. This discussion is restricted to the electrical war training programs, designed to train or upgrade engineers, journeyman electricians, and technicians, in the various war and essential industries of California*. Emphasis is placed on shipbuilding, maintenance, construction, and operation.

The chief objective of the program was to supply sound training as a basis of attack on personnel shortages and deficiencies in war or essential industries. From the beginning, in February 1941, it was obvious that the desperately needed technically trained workers could not be produced overnight. Three major aims were practical:

1. To bring practicing engineers up to date on new developments
2. To assist engineers in changing over to electrical or radio engineering from other fields.
3. To upgrade skilled mechanics and technicians.

In general, instruction was offered on three levels:

1. Courses for skilled mechanics and technicians: These men were not always high school graduates; however, they had completed craft training, had considerable practical experience in their positions, and were potential or current supervisory personnel. Frequently they were prepared poorly in mathematics and physics so that courses were, of necessity, descriptive in nature. Thus the educational program expanded horizontally, that is, additional courses were limited to the same technical level rather than progressing in technical difficulty.

2. Courses for students having satisfactory backgrounds in mathematics and physics, such as those with junior college training: At this level the sequence of courses expanded vertically, that is, they increased in technical difficulty as do ordinary college courses.

3. Courses for practicing engineers: Successive courses progressed vertically at a much faster pace than at the two subprofessional levels.

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* See "Training for War Industries," mimeographed edition, September 1945, University of California, for comprehensive discussion of entire program.

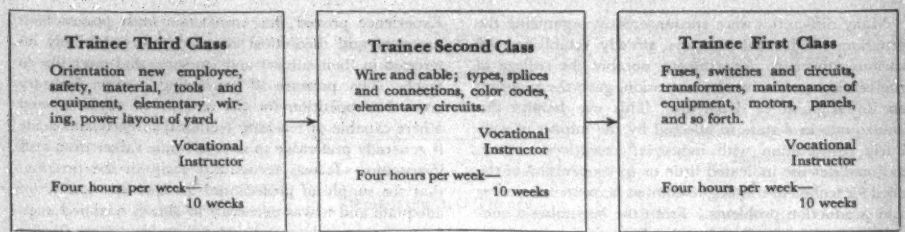

Trainee Third Class
Orientation new employee, safety, material, tools and equipment, elementary wiring, power layout of yard.
Vocational Instructor
Four hours per week—
10 weeks
Trainee Second Class
Wire and cable; types, splices and connections, color codes, elementary circuits.
Vocational Instructor
Four hours per week—
10 weeks
Trainee First Class
Fuses, switches and circuits, transformers, maintenance of equipment, motors, panels, and so forth.
Vocational Instructor
Four hours per week—
10 weeks

Figure 1. Suggested educational programs for shipyard trainee electricians for large and small organizations (craft training)

The total enrollment was of less significance than was the quality of the trainees and their practical opportunity to use the training to advance the war effort. Selection of trainees was made with as much care as the wartime rush would allow, and prerequisites for courses were written to screen out applicants who were not equipped for the work. For professional courses presenting subjects normally given as part of an engineering curriculum, normal academic prerequisites were used. For many low-level but badly needed courses, such as those designed to develop supervisors or technical workers, it was necessary to broaden the prerequisites to admit mature students with practical experience, otherwise the trainees of greatest potential use to industry would have been eliminated. In general, the minimum prerequisite was high school graduation or equivalent education,* or satisfactory completion of a qualifying examination in subject matter basic to the work of the course, and employ (or qualifications for employment) in a war industry.

A student was admitted to these war training courses according to an estimate of his probable success made by the supervisor and based on:

1. An analysis of the applicant's background of education and experience as shown by his application blank.
2. His score on qualifying examination covering knowledge essential to the course.
3. A personal interview when information from the first two sources was inconclusive.

No one of these three means of rating applications provided accurate measures of likely student success. An industrial training program less rushed for time well might study, with the help of a testing specialist, both vocational tests and standardized achievement tests as a means of student selection. As checked by sampling of application blanks, the average student had a formal educational background of 13.2 years (university sophomore standing) in contrast to the average schooling of 8.6 years of the adult male population.

Electrical classes generally consisted of 2 to $2^1/_2$ hours of lecture or 3 hours of laboratory and met once a week for 15 to 20 weeks. Instruction was conducted at various technical levels in electrical theory, design, operation, maintenance, and repair, and in the fields of power, radio, and industrial electronics. Public classes were conducted in war training centers such as Berkeley, San Francisco, and Long Beach, and in various highschools and junior colleges located near vital industries. The public classes were effective in training both engineers and electricians for war industries which lacked sufficient personnel to support individual classes. These classes usually were conducted at a higher technical level than the in-plant classes, many were of strictly graduate level, and advanced courses were given in communications, ultrahigh frequency phenomena, and industrial electronics. Public courses were of necessity more general than in-plant courses, and inevitably included material of secondary interest to some of the class members. As the national organization for war matured, the need for training shifted from preparation for initial employment in war production to training aimed at improving the knowledge and efficiency of employed personnel. The different needs, together with the growing recognition of the war training program by industrial management, fostered in-plant courses as an effective means of providing training in specific requirements for satisfactory performance of a department or of a group of employees within a given plant. Members of in-plant courses were a homogeneous group as far as interests and production experiences were concerned. This established effective learning situations. The instructor, after consultation with management and an inspection of the plant, knew the makeup of his class, the jobs being done by the students, and their relationship to other jobs in the plant. Thus it was possible to plan course content to achieve specific results and to avoid irrelevant material. Classes were held on company time, part time, or after work.

* Equivalent education was interpreted as completion of a substantial course of study in the field covered by the course, such as completion of correspondence or class courses conducted by an institution of recognized standing (International Correspondence Schools, various university extensions); completion of the craft training program; or recognition of accomplishment, such as holding a license (licensed marine engineer, commercial radio operator); or service in the Armed Forces with a rating or rank of commissioned, warrant, or petty officer.

Many difficulties were encountered in organizing the program. Industrial contacts already established by various university departments, notably the college of engineering and university extension, gave the program an initial point of departure. This was helpful but inadequate in a state so affected by the impact of war. Early consultation with industrial executives vital to national defense indicated little or no recognition of the need for technical training to combat personnel shortages and production problems. From the beginning a continuous and aggressive plant-by-plant canvass was carried on by the supervisors who were qualified professionally and practically to recognize production problems and training needs, and to recommend possible solutions. Helpful information on local war contracts and manpower needs was secured from chambers of commerce, manufacturing associations, engineering societies, war production councils, the War Manpower Commission, United States Employment Service, and other federal agencies. Local "men wanted" advertisements, state employment statistics, and manpower surveys were studied. Courses in technical subjects related to an industry were offered in the vicinity of the larger plants, and local facilities were established in strategic industrial areas in anticipation that technical training would gain acceptance as a means of improving production.

Theoretically, the determination of training needs should be a function of the training department of the company concerned. Unfortunately, few such departments in large war plants were close enough to all other divisions in their company to be cognizant of all training needs. Furthermore, training departments in new plants were forced by circumstances to devote most of their attention to training large numbers of employees in a few manual skills. As a result, the needs of rather small groups for specialized training often were overlooked.

The success of the program depended to a large measure on the type of instructors it was possible to recruit.

Table I. Typical 3-week lecture schedule for course given by University of California in co-operation with United States Maritime Service as part of Engineering Science and Management War Training Program

Subject	Number of Hours Per Lecture
Heavy a-c machinery	2½ (2 lectures)
Engine room electric equipment	2½ (3 lectures)
Degaussing systems	2½ (1 lecture)
Pressure reducing valves, feed pump governors, and thermostatically controlled valves	2½ (1 lecture)
High pressure steam boilers	2½ (2 lectures)
Combustion and superheat control and feedwater regulators	2½ (1 lecture)
Compressors and pumps	2½ (1 lecture)
Boiler feedwater treatment	2½ (1 lecture)
Lubrication and fuel oil	2½ (1 lecture)
Fire protection	2½ (1 lecture)
Steam turbines	2½ (2 lectures)
Refrigeration	2½ (1 lecture)
Purification of turbine oil	1¼ (1 lecture)
Steering engines	1¼ (1 lecture)

Experience proved that instructors must possess both practical and theoretical knowledge, be genuinely interested in their subject and students, and must like to teach. The pressure of expanding western industry created competition for the services of engineers and others capable of teaching technical subjects and made it generally preferable to use part-time rather than staff instructors. It was recognized early in the program that the supply of professional teachers was totally inadequate and it was necessary to obtain qualified engineers from various sources. Securing a competent staff, even on a part-time basis, was difficult and at times seemed almost impossible. Manufacturers of equipment being installed on the ships supplied men to teach courses on installation and operation. Power utility engineers discussed problems of electrical maintenance. Plant engineers discussed yard layout, maintenance, and current problems, and officers were obtained from the services to discuss equipments classified as to security.

Acknowledgment and appreciation is due the electrical manufacturers and utility companies for allowing their heavily loaded engineers to undertake the additional burden of instructing in the program. Most of the success of the electrical program can be attributed directly to this farsighted policy of co-operation.

In a program largely dependent upon industrial personnel for a teaching staff, rates of compensation must take into account the instructor's position and salary, his professional or technical education and experience, and the total amount of time he is to devote to course preparation, local travel, and classroom teaching. The civilian aspect of the war has been fought on a pay basis. Under similar conditions in the future, college-level training must meet the going wage which the instructor can earn at his profession in the community, or lower its standards by hiring men who cannot meet industrial requirements.

Aggressive publicity, both in making war industries aware of the war training program, and in the promotion of scheduled classes, played a major part in encouraging greater use of these courses. In completing arrangements for in-plant courses, the university supervisor included an offer to supply posters, individual course announcements, house organ stories, and other helpful publicity material, and also emphasized to company executives the importance of seeing that this material was distributed properly and was supplemented with promotional aids of their own.

One of the greatest obstacles at the beginning of the program was the indifference, and in some cases hostility, of management toward university sponsored training. Many felt that the workers should be forced to learn the "hard way," without the benefit of free education. Some superintendents frankly stated that they wanted their workers kept in ignorance lest they become discontented with their work, or lest they demand higher wages. However, one or two courses were usually

sufficient to establish the worth and need for training. Subsequent courses received less opposition, and, toward the end of the war, training on company time with Navy or Maritime Commission approval was exceedingly helpful.

At the beginning of the program, Washington officials of the armed services were of the opinion that the program would be of no value to military or naval establishments. However, many local civilian electrical superintendents felt quite differently. When the ponderous wheels of government finally revolved, 300 students were enrolled in electrical classes at each of two Navy yards, much to the amazement of the officials concerned. These classes should and could have begun at least three years sooner.

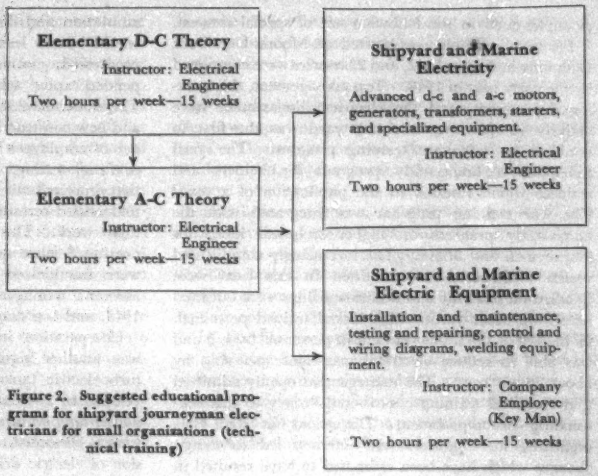

Elementary D-C Theory
Instructor: Electrical Engineer
Two hours per week—15 weeks
Elementary A-C Theory
Instructor: Electrical Engineer
Two hours per week—15 weeks
Shipyard and Marine Electricity
Advanced d-c and a-c motors, generators, transformers, starters, and specialized equipment.
Instructor: Electrical Engineer
Two hours per week—15 weeks
Shipyard and Marine Electric Equipment
Installation and maintenance, testing and repairing, control and wiring diagrams, welding equipment.
Instructor: Company Employee (Key Man)
Two hours per week—15 weeks

Figure 2. Suggested educational programs for shipyard journeyman electricians for small organizations (technical training)

Student response to electrical training always has been good. In fact, in many plants the class attendance has been many times original estimates. Men have shown an eagerness to acquire technical backgrounds for their vocational skills in spite of obstacles such as poor company attitude, transportation, housing, sickness, overtime, and constantly changing work schedules.

The most important factor determining the success of in-plant programs was the attitude of the electrical superintendent. In planning future programs one should plan to spend much time and effort in convincing supervisors and top management of the value and need for technical training, and the now quite generally recognized fact that technical training does *increase* production. One also should make every effort to begin large programs as early as possible, for the benefits of training often are delayed. Too often we have encountered the belated realization that, "this training is needed badly, but the course should have been given a year ago to do any good now!" Another source of friction was that one plant occasionally would find its best men stolen by a competitor and, therefore, would be reluctant to serve as a school for the industry. This circumstance can be overcome only by close co-operation between the various government agencies, labor representatives, and management, and the adoption of an overall training policy for a given industry.

It is difficult to evaluate any industrial technical training program. Ships are not launched days ahead of schedule because of one electrical class, and although technical instruction is admittedly necessary in the electrical field, any single class may add but little to the reservoir of knowledge available to a particular group. Nevertheless, technical knowledge has been the driving force behind the production miracle recently wrought, and each class contributed its increment. War training helped to meet the shortage of engineers and skilled technicians, and helped to maintain a group of adequately trained men in the electrical departments. In addition, it effected innumerable savings or innovations, some of which are mentioned later in this discussion.

Electrical training programs were conducted in 21 shipyards throughout the state of California. This included all but the smallest yards or ship repair bases. Some of the larger yards established electrical training organizations, constructed classrooms, and in one instance, equipped a modest electrical laboratory. In the majority of cases classrooms provided by the yard training departments were used. Some of the smaller yards had no training facilities, and a portable blackboard in one corner of the electric shop, or mold loft, sufficed. Most classes were conducted under very unfavorable conditions. Inexperienced instructors carried on in spite of ever-present distractions such as wide variations in attendance due to overtime, men dirty and tired from the day's work, and high noise levels. A spot check at one location indicated that an average of $19\frac{1}{2}$ steam trains passed within a few feet of the class during the two hour period. Considering the handicaps, the results are surprising indeed.

A careful study indicates high correlation between the intensity of electrical training and the success of the yards. The correlation is most apparent when one compares the success of the training with the abilities of the yards to change over from simple types of vessels to the complicated succeeding types or to repair work. Lack of space precludes detailed treatment; however,

examples cited in the following are of special interest.

Electrical training was started at Moore Dry Dock Company in August 1942, and 23 courses were completed by the early part of 1944. Top management, the training department, and the electrical department were actively co-operative, and this yard was the first to establish an adequate training program. The yard developed a home-study program for helpers and trainees which resulted in the publication of a text.[1] The war training program was integrated with the home-study program on higher technical levels for journeymen and above. The increasingly complicated vessels constructed and outfitted in this yard were handled on schedule and additional ships were outfitted here from other yards which lacked trained personnel. In the fall of 1943, this yard cut its personnel by 1/3 and was able to reduce electrical man-hours per ship by about 20 per cent. The management openly admitted that electrical training contributed largely to this outstanding accomplishment. Discussions in one class organized for engineers and foremen led to design changes which have been estimated to have resulted in the saving of over a million dollars on a 65-ship contract. Later an attempt was made to economize by employing a subcontractor. The contractor's men were not trained properly and the work had to be torn out and redone by the regular workers in the yard.

In contrast, consider one of the shipyards in Southern California. Here an unsuccessful attempt was made to prepare marine electricians for the change from Liberty to Victory ships in January 1944. Only when difficulties became unsurmountable was Engineering Science and Management War Training given a real chance. A concentrated program consisting of three two hour meetings per week on company time was begun—but this was too late to prevent serious delay in the outfitting of the first ships in a series of vitally needed naval vessels. As a result the yard failed to meet production schedules. Four hulls were towed 500 miles to the San Francisco area, and five were towed 1,000 miles to Vancouver, Wash., for outfitting. This waste of priceless time, not to mention money, could have been avoided by proper and timely training.

The most comprehensive technical program was organized at Bethlehem Steel Company, Terminal Island. The first step was a review of the plant's existing craft training and its further training needs by a plant committee made up of the assistant manager, the sales manager, management's representative, the superintendent of hull repairs, and the superintendent of machinery repairs. Careful plans for instruction and for selection of trainees were worked out with the help of the Engineering Science and Management War Training supervisor, resulting in a program which included marine electric equipment, marine piping, marine Diesel engines, steam turbines, and steam boilers and auxiliaries.

The assistant manager reviewed each qualifying examination and disqualified those who, in his opinion, would benefit least from instruction. As the program progressed, permission to take successive courses depended upon achievement in the preceding course. The students were limited to qualified men in the repair and new construction departments plus a specified number of employees from associated departments, such as drafting, testing, and purchasing. This was done so that representatives of the associated departments would understand certain engineering problems which affected their work. The instructors were selected by Engineering Science and Management War Training, and were interviewed and approved individually by the assistant manager. This program began in March 1944, and was conducted on company time.

Co-operative instruction with the armed services was another significant part of the program. The turboelectric tankers and turbogear Victory ships developed in 1943 and 1944 were designed to operate at higher temperatures and pressures than marine engineers were accustomed to handling. Furthermore, the inclusion of electric drive and electric auxiliaries proved to be formidable innovations. In order to prepare engineers to operate these ships, the United States Maritime Service established a school at Sausalito. Licensed marine engineers attended this school for three weeks during which time they were transferred to the payrolls of the United States Maritime Service. Day classes were conducted by United States Maritime Service officers and much time was spent in the partially completed hulls, studying prints and piping layouts, trial runs, and so forth. Technical lectures were given by engineers who were employed by the manufacturers supplying the steam and electric equipment being installed in the ships. This co-operation with the United States Maritime Service brought the latest and best technical information to the students and gave them a satisfactory combination of theory and practice. A second Maritime Service school was established at Richmond, and a third on the east coast. Although this third school was organized with the assistance of a former University of California Engineering Science and Management War Training supervisor, and a former officer from the United States Maritime Service school at Richmond, subsequent supervision was handled by an eastern university. The scope of subjects and number of hours devoted to each are illustrated in the typical three-week schedule shown in Table I. Classes were given at unusual hours as the result of compromise often necessary when employing practicing engineers as part-time instructors. The Sausalito and Richmond school terms subsequently were lengthened to four weeks. A total of 1,248 marine engineers attended the two schools during the period September 20, 1943, to June 30, 1945. This combination of training was considered so valuable that, with the termination of the war training program, the War Shipping Administration contracted with engi-

neering extension to continue this instruction while the shortage of marine engineers lasts.

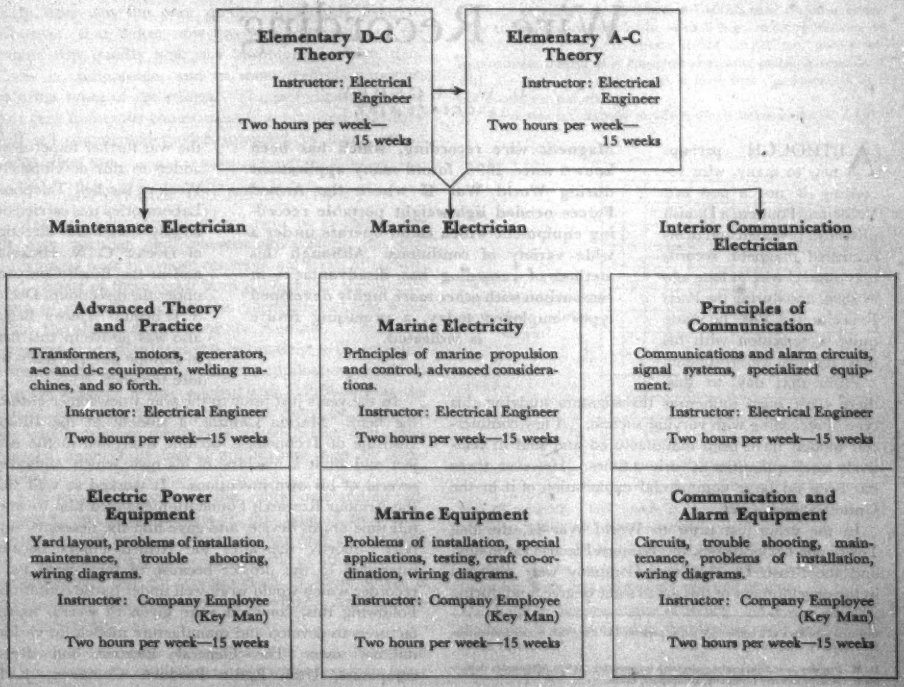
Similar co-operative instruction was provided for United States Navy officers about to be assigned to engineering positions on combat vessels at the Operational Training School, Treasure Island, and at the Naval Training Center, Terminal Island. A total of 347 officers was enrolled in these classes before they were concluded because of changes in the Pacific theater.

Co-operation with locals of the International Brotherhood of Electrical Workers proved an efficient way of training large groups of workers, especially those employed in smaller industries. The psychological reaction of students was much better than that of many in-plant courses. In these classes, as in the public classes, there was no incentive to take training in order to achieve advancement in an organization simply by having attended a course of instruction.

During the early months of war training, particularly in the Richmond area, much time and energy was lost because of the lack of co-operation and even hostility between War Production Training and Engineering Science and Management War Training. The former was set up on a "vocational" level, yet its upper limits were not defined. As a result there was much conflict over courses in electrical theory at the lower levels. A clear-cut separation should be made at the journeyman level. This separation was effected in the program as it developed, but a consecutive, integrated training pattern never evolved. As a result of consultations with electrical superintendents, training directors, instructors, and supervisors, training programs were worked out to co-ordinate effectively vocational and technical training for both large and small organizations. Although the outlines shown in Figures 1, 2, and 3 never were achieved in their entirety, they are included for future reference.

In addition to formal instruction, all classes served as a clearing house for problems arising daily in the war industries in which the students were employed. In-plant classes obviously could stress particular troubles in a particular plant, yet the public and union-sponsored courses had their share of special benefits. For example,

Figure 3. Suggested educational programs for shipyard journeyman electricians for large organizations (technical training)


Elementary D-C Theory
Instructor: Electrical Engineer
Two hours per week—15 weeks
Elementary A-C Theory
Instructor: Electrical Engineer
Two hours per week—15 weeks
Maintenance Electrician
Marine Electrician
Interior Communication Electrician
Advanced Theory and Practice
Transformers, motors, generators, a-c and d-c equipment, welding machines, and so forth.
Instructor: Electrical Engineer
Two hours per week—15 weeks
Electric Power Equipment
Yard layout, problems of installation, maintenance, trouble shooting, wiring diagrams.
Instructor: Company Employee (Key Man)
Two hours per week—15 weeks
Marine Electricity
Principles of marine propulsion and control, advanced considerations.
Instructor: Electrical Engineer
Two hours per week—15 weeks
Marine Equipment
Problems of installation, special applications, testing, craft co-ordination, wiring diagrams.
Instructor: Company Employee (Key Man)
Two hours per week—15 weeks
Principles of Communication
Communications and alarm circuits, signal systems, specialized equipment.
Instructor: Electrical Engineer
Two hours per week—15 weeks
Communication and Alarm Equipment
Circuits, trouble shooting, maintenance, problems of installation, wiring diagrams.
Instructor: Company Employee (Key Man)
Two hours per week—15 weeks

conclusions reached in one public course made it possible for a Bay area engineer to fly to Southern California and activate the electronic equipment on a group of B-17s which long had been grounded. Discussions in one union-sponsored course led to the correction of resonant currents and resultant frequent faulting in a large transformer serving an arc furnace which supplied castings for two large Navy yards, and every failure required a shutdown of at least two weeks for repairs.

No university credit was given for war training courses but students successfully completing them were given "certificates of completion." Although certificates were given for satisfactory completion of individual courses, an effort was made to encourage the student to complete substantial work in the field, and rather elaborate certificates were awarded upon the completion of 125 class-hours of instruction. This usually represented completion of four courses and required approximately one two hour meeting per week for a year.

The success of the electrical program was due largely to the man-hours spent by the supervisors talking with workers and students, determining training needs, selecting capable instructors, publicizing the program, and actively supervising the organization and conduct of each course. This resulted in a relatively high cost per student hour, but was repaid well in efficiency of instruction and in respect and esteem for the program. Many executives have taken the time and effort to write letters of appreciation expressing the opinion that the program made a material contribution to the war effort.

REFERENCE

1. Practical Marine Electricity (book), S. N. LeCount, H. S. Dusenbery. The Macmillan Company, New York, N. Y., 1945.

Wire Recording

D. W. PUGSLEY
ASSOCIATE AIEE

Magnetic wire recording, which has been known since 1896, found many applications during World War II where the Armed Forces needed lightweight portable recording equipment which could operate under a wide variety of conditions. Although this method of recording has disadvantages in comparison with other more highly developed types employed today, a promising future is indicated.

ALTHOUGH perhaps new to many, wire recording is not a new art. Valdemar Poulsen, a Danish physicist, invented and demonstrated magnetic recordings on steel wire as long ago as 1896, and during the Paris Exposition of 1900 he made quite a sensation with his now famous Telegraphone.

From that day to this, there have been numerous investigators studying this type of recording with varying success. A few commercial models have been manufactured and sold in relatively small quantities at various times. However, there has been no large commercial exploitation of it in the United States as yet.

In the years just prior to World War II, the Bell Telephone Laboratories, the Western Electric Company, and the Brush Development Company were engaged in the development of this art to some degree, and during the war further impetus was added to this development. Work at the Bell Telephone Laboratories was carried out largely under the direction of Doctor C. N. Hickman and at the Brush Company under the direction of Doctor S. J. Begun. Doctor Begun also was active in this field in Europe several years before the war.

In the years just prior to the war a newcomer entered the field. Marvin Camras, a student at the Illinois Institute of Technology, became interested in the subject and built a machine of his own which embodied several of his own inventions. It worked so well that the Armour Research Foundation engaged him to work full time on his device, and gave him the necessary support. Shortly thereafter the Armed Forces became interested in the project because of their need for a recorder which would work well under battle conditions. Following this, contracts were given to several manufacturers to develop and manufacture models for various military uses. The General Electric and Brush companies, Utah Radio Products Company, J. P.

Essential substance of a conference paper presented at the AIEE winter convention, New York, N. Y., January 21–25, 1946.

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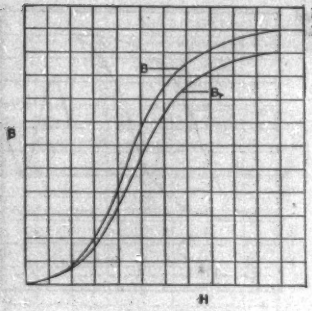


Figure 1. Typical B-H and B_r-H curve for iron

Seeburg Corporation, Radiotechnic Laboratory, and others, produced various types of wire recorders for military purposes.

So much was learned during this program about the subject that the wire type of recorder now promises to be a major competitor of other recorders in the postwar world for many applications.

One of the chief disadvantages of this recorder in the early days was the poor quality obtainable from it. However, that defect now has been overcome to the extent that quality now can be obtained which definitely is comparable, and in some respects superior, to other types of recordings. This is indicated by the fact that numerous concerns have announced that they will sell commercial models intended for home use in the postwar era.

ADVANTAGES AND DISADVANTAGES

Magnetic wire recording, as might be expected, has its own peculiar and inherent advantages and disadvantages over the more conventional types of recording. Some of these result from the fact that the mechanism of recording is magnetic phenomenon, and some from the shape and size of the medium. These advantages and disadvantages ultimately will establish wire recording in its most logical applications where it can do a better job at a lower cost. Probably at the outset, however, some applications may be exploited for which another medium is suited better, and, conversely, some of its logical applications may be overlooked.

Following are some of the more outstanding advantages and disadvantages of this type of recording. These are not listed as being peculiar only to this type as some of them are also characteristic of other methods of recording, but the combination of these items is peculiar to magnetic wire recording. Among the advantages are:

1. Long uninterrupted playing time with a relatively small record. By use of a small diameter wire an excellent space factor can be obtained. For instance, an hour's recording, with good fidelity, can be placed on a spool approximately three inches in diameter and five eighths inch thick.

2. Very simple recording procedure. This is apparent especially to those who have experimented with disk recorders which use a cutting head.

3. Medium may be used innumerable times for new recordings. Thus, when a recording has served its purpose it may be used as a new blank. It need not be thrown away.

4. Recording is erased easily if desired, thus making possible correction of mistakes or insertion of changes. The saving in money because of this feature, especially for the amateur, is apparent.

5. Large number of playbacks possible without appreciable deterioration of quality. Disk recordings have been relatively poor in this respect in the past. Wire recordings reportedly have been played hundreds of times with little deterioration.

6. Medium is spliced very simply thus making dubbing-in easily accomplished. This again is a matter which is chiefly of importance to the amateur.

7. Good frequency response. Response to 6,000 or even 10,000 cycles per second can be obtained easily with quite low wire speeds. Higher response can be obtained by simply increasing the wire speed.

8. Low noise level. Alloys such as are in process of development by the General Electric, Armour, and National Standards companies have a signal-to-noise ratio of 40 to 45 decibels. Other alloys conceivably can be developed which may do even better. (The term signal-to-noise ratio, as used here, refers to the over-all ratio between root-mean-square signal output and root-mean-square noise output of a complete machine, properly equalized, with the signal recorded at such a level that the distortion does not exceed ten per cent.)

9. Recording is relatively unaffected by vibration, shock, or position of recorder. This makes it especially valuable for use on airplanes, trains, and other vehicles.

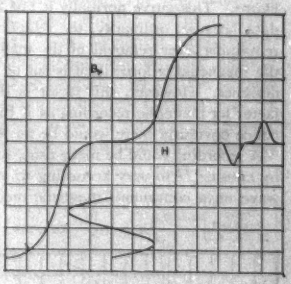


Figure 2. Distortion resulting from recording about origin

10. Portability of equipment. A complete recorder and reproducer can be made easily which occupies a relatively small volume of space and weighs only about 30 pounds.

11. Relative indestructibility of record. As it is a steel wire, the record is not damaged or destroyed as easily as some other types of records.

12. Unaffected by extremes in temperature.

Among the disadvantages are the following:

1. After recording and after each playing, the record must be rewound before being played. Rewinding time may be much faster than playing time, but it is still a factor to be considered.

2. Medium is difficult to drive. Clever design is necessary to avoid "wow," to avoid wire from becoming slack or tangling, and to avoid breakage. However, such drives can be and have been designed.

3. Medium is not as convenient to use as a disk. The incorporation of a complete magazine loading feature overcomes most of this disadvantage, but complicates the design and adds to the cost of the record.

4. A record is not reproduced easily in large quantities. The most feasible method for reproducing records in large quantity appears to be by rerecording from a master record. A substantial number of recordings can be made simultaneously by this method, and the wire speed during recording possibly can be faster than normal, thus shortening the time required. However, there is much development to be done before this method of reproduction will compare favorably with the manufacture of disk records.

5. The blank medium (before having a recording placed on it) relatively is quite expensive as compared with mediums such as disks. This cost may decrease considerably, but improvement in this direction probably will follow use of less wire per record (by using lower wire speeds) rather than reduction in cost of wire, inasmuch as drawing of fine wire is an old established art and large quantities have been drawn for other uses.

HOW IT WORKS

In Figure 1 is shown a typical *B-H* (magnetic flux density–magnetic intensity) curve for iron and also a B_r-H curve. The B_r-H curve shows the relationship between remanence and applied magnetomotive force corresponding to the *B-H* curve shown at the left of the figure. This curve normally is not shown in magnetic data because, ordinarily, the relationship between flux remaining after removal of the magnetizing force and the magnetizing force itself is not of much value to the designer. However, this factor is the most important factor for magnetic recording as if there were no remanence obviously there would be no recording.

A recording could be made using such a characteristic by causing H to vary according to an impressed sound wave on a continuous magnetic medium being drawn rapidly past the source of magnetomotive force. This would leave the medium magnetized along its length with each increment having a value of B_r corresponding to the applied H at the instant that increment was passing through the field. However, the recording would be very distorted because of the radical curvature of the B_r-H curve as it passes through the origin (see Figure 2).

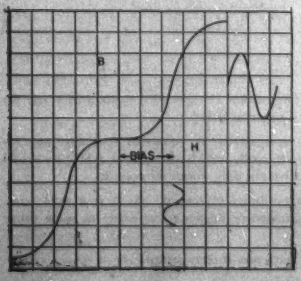


Figure 3. Distortion reduced by superposition of constant biasing field

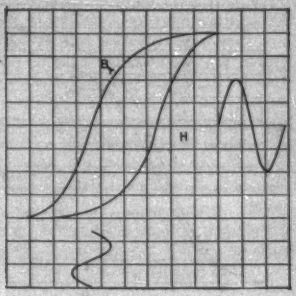


Figure 4. Method to increase dynamic range

One solution is to place a d-c biasing field on the medium prior to recording which then causes the recording to take place on the straight-line portion of the B_r-H curve as shown in Figure 3.

A better method, resulting in a greater dynamic range, is first to saturate the wire and then to magnetize it in the opposite direction before recording. This method is shown in Figure 4.

The latter method is the one which has been used in the past by most investigators. However, the method used by Camras in his machine, and the method which is used most extensively today, is to use no d-c bias, but instead to superimpose a supersonic signal at a frequency of 30 to 50 kc on the medium simultaneously with the signal to be recorded. By adjusting the various parameters to their proper value, an effective B_r-H curve (Figure 5) can be obtained. Thus recordings with low distortion are possible. The exact method by which the supersonic bias straightens out the B_r-H curve will not be explained in this article, but it does so effectively as shown by Figure 5 which is a curve derived from experimentally obtained data.

Figure 6 illustrates a block diagram of a complete wire recorder. As can be seen from the diagram, the signal from the microphone is amplified and applied to the recording head, which is one form of an electromagnet. Simultaneously, the supersonic frequency also is applied. On playback the magnetized medium is run through the same recording head, which now acts as a pickup coil. The voltage induced is amplified by the same amplifier and reproduced in the loudspeaker.

The erase coil is also in evidence. It is located just before the recording head and is energized only during recording. This coil is energized with the same supersonic oscillator used for recording. The erasing simply

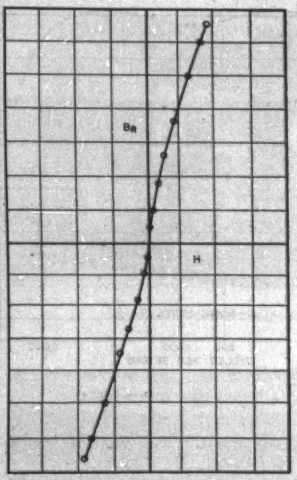


Figure 5. Effective B_R–H curve using supersonic bias

consists of demagnetization by means of the high-frequency a-c field.

Wire usually is magnetized longitudinally. This magnetization is represented pictorially in Figure 7, which also shows how the flux from the recording head enters the wire. The small air gap shown forces the flux upwards from the laminations and longitudinally through the wire. Thus, after magnetization, the wire consists of a series of alternate poles, the spacing of the poles depending on the frequency recorded and the speed of the wire. For a given wire speed there are two main factors limiting the highest frequency that can be recorded. One of these is self-demagnetization of the wire and the other is the aperture effect of the gap. Self-demagnetization is a function of the wire diameter, while the aperture effect naturally is a function of the gap width. Machines produced during World War II commonly used wire of 0.004-inch or 0.006-inch diameter and gaps of 0.002 inch to 0.004 inch, with wire speeds varying from three to six feet per second.

USES DURING THE WAR

Wire recording had almost what might be termed a rebirth during the war. The Armed Forces desperately needed recorders which would operate satisfactorily on airplanes, on battleships, in jeeps and trucks, and in similar places. Wire recorders met the reqfirements with marked success. Even war correspondents carried special portable models to the front lines and secured on-the-spot recordings of actual battles. Most people, often not realizing what it was, undoubtedly have heard many recordings over the radio which were taken on wire in actual combat. There also have been numerous other military instances for the use of wire recording.

QUALITY OBTAINABLE FROM WAR MODELS

Several different models were used during the war, but in practically all cases the primary intended usage was for recording of speech. Nearly all these recorders, therefore, were designed specifically for speech, and so in general were not entirely satisfactory for music. The frequency range was restricted, and tolerances were not held close enough to reduce "wow" to satisfactory music levels. A typical frequency response curve is shown in Figure 8 for a wartime recorder. This curve is for a wire speed of six feet per second. A more restricted response is obtained at a wire speed of three feet per second. Most of these recorders had about this frequency response, although one model, designed and produced by the Brush Company for higher fidelity, had the response shown in Figure 9. The average dynamic range of these machines was about 35 decibels which is comparable to average prewar disk recordings. The higher fidelity machine had about 40 decibels. "Wow" was held to a point where it was not at all noticeable on speech, but on many machines would be objectionable on music.

Figure 10 shows various wire recorders built during the war period. These do not represent all the models built, nor all the concerns building them, but do show a typical cross section.

QUALITY POSSIBLE TO OBTAIN

Postwar commercial wire recorders will be much different than wartime models. For one thing the quality will be much better, and the cost undoubtedly will be much lower. One significant improvement made recently was the development of much superior alloys for the recording medium. By the use of these new alloys, satisfactory frequency response can be obtained at wire speeds as low as two feet per second, and, if still better response is desired, it is necessary only

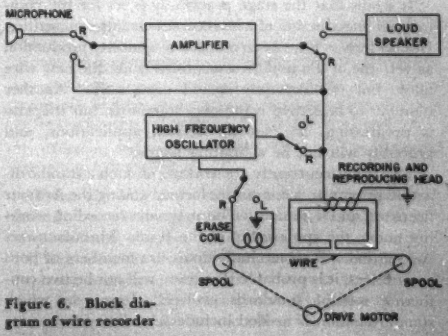


Figure 6. Block diagram of wire recorder

to pull the wire a little faster. These new alloys also have a good dynamic range (about 40 to 45 decibels) and distortion can be held down, on the average, to about three to four per cent total harmonic distortion. Using this wire at a speed of two feet per second, an hour's recording can be contained on a spool which is but three inches in diameter and five eighths of an inch thick.

In all fairness it should be pointed out that as yet these new alloys have not been produced in production quantities, the data having been taken on sample lots. However, there seems to be no fundamental reason why this type of wire cannot be produced on a large scale once the proper controls have been established in the factory.

"Wow" is a function of excellence of design and maintenance of tolerances during manufacturing, and there

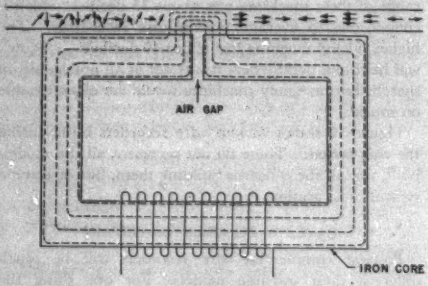


Figure 7. Recording

is no reason to suppose that good commercial models now under development by several companies will have more than one half of one per cent of "wow."

STANDARDIZATION

It seems that the stage practically is set for the commercial introduction of wire recorders in large quantities. Not all factors have been reduced to quantity production as yet, one of the notable exceptions being the new wire alloy, but this certainly should come soon. Another item yet to be settled is industry standards, but this also is progressing, at least for certain applications, and probably will not be a limiting factor.

Two groups currently are working on such a standardization program; a committee formed among the Armour licensees, and a committee on magnetic recording working under the sponsorship of the Radio Manufacturers Association. As some individuals are members of both committees, it is probable that there will not be two conflicting sets of standards evolved. Items on which standardization is needed include wire dimensions, wire

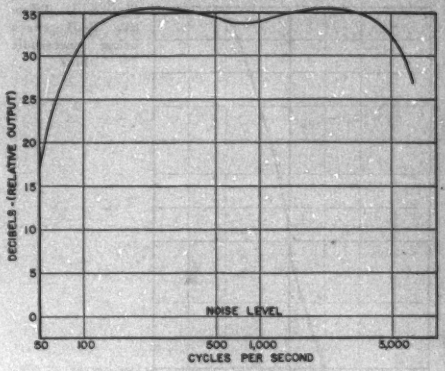


Figure 8. Frequency response curve

speed, size and shape of spool, and magnetic characteristics of wire.

Further information on quality may be found in an article by L. C. Holmes and D. L. Clarke (*Electronics*, July 1945). These men have investigated, among other things, distortion in magnetic recording by intermodulation methods, magnetic properties of recording media, proper equalization for highest signal-to-noise ratio, effect of speed of the medium, and erasing means for media with high coercivities.

POSSIBLE FUTURE USES

It should be noted that possible future uses are referred to, and not just future uses. Very likely some of the possible applications enumerated will prove to be noncompetitive with other methods of recording, and, on the other hand, probably other eventual applications are not listed.

1. Home recording. The extreme simplicity of recording, plus the ability to reuse the records, makes wire recording ideal for the amateur who likes to make his own recordings, record weddings, historical talks or events, and so forth. The small size

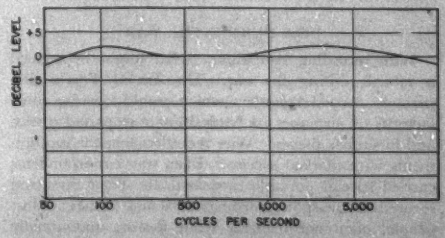
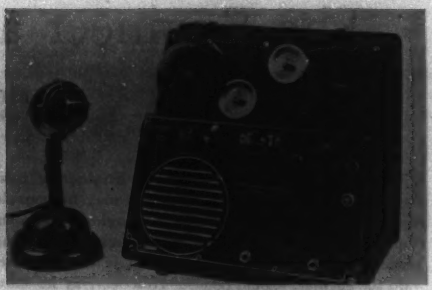


Figure 9. Over-all frequency response of wide range magnetic recorder

A—Radiotechnic Laboratory model 22



B—Armour model 50

C—Radiotechnic Laboratory model 55

D—General Electric model 51

Figure 10. Types of wire recorders

and portability of the equipment are also important considerations in this application.

2. Broadcast station usage. The fact that radiobroadcasting stations have a definite need for such a recorder is evidenced by the fact that many of them already have bought, and are using, wartime models, even though their use is very limited inasmuch as they were not designed for such application.

3. Over-the-counter records. Considerable thought and effort even now is being put forth to develop this business to the point where records on wire can be bought and sold as universally as disk records are now. It would appear that this application is somewhat further in the future than some of the others because of its many phases, but considerable effort is being expended on it.

4. Commercial and public announcements. Investigations have been, and are being, made to exploit the advantages of repetitive announcements in stores, parks, streets, and other places where people gather.

5. Pocket recorders. Very small pocket recorders can be made for recording interviews and the like. The Federal Bureau of Investigation may find such a device useful. Concerns engaged in making surveys also are looking into this possibility.

6. Record players on vehicles. Records on wire make possible the use of record players on airplanes, cars, trains, boats, and so forth. This may prove to be a fruitful field.

7. Automatic recording. Automatic recording of items such as court proceedings, telephone conversations, instructions to and from aircraft, freight car and other traffic records, is accomplished easily.

8. Juke boxes. It is conceivable that this problem might be solved better, or more economically, by the use of wire rather than disks.

9. Industrial uses. There are a multitude of industrial needs, including recording of stresses, that may prove to be met best by wire. Recorders even now are being used in such applications.

10. Educational uses. Machines may be used in schools and in homes for teaching music, dancing, language, presenting talks by famous persons, and so forth. This field is very important.

11. Teaching and amusing the blind and sick. The possibilities here are most intriguing.

These are only a few of the many applications that already have been suggested. Others undoubtedly will occur to each of you.

From all indications, it appears that Poulsen's Telegraphone is about to come into its own at last. The next few years well may see this new industry assume a prominent position in the recording field.

The Engineer and Management

LEE H. HILL
FELLOW AIEE

The engineer's relationship with management may be considered from three angles: the engineer as an employee of management, the engineer as an engineer, and the engineer as a candidate for managerial positions. However, as he moves further and further away from his slide rule up into the managerial brackets, he frequently finds that he is ill-equipped to handle the personal elements which enter into an executive position. Perhaps the solution is the inclusion of more of the so-called "cultural" and "human relations" subjects in engineering education.

EMOTIONALLY, the engineer is a human being much the same as other employees in the plant. Management's attitude toward the engineer should be based on the fact that the engineer is a person, not an engineer as such; and all the principles which have become commonplace in discussions of employer-employee relations apply to the engineer as well as to the lathe hand. The engineer dislikes unfair treatment from his superior as much as the lathe hand does; he is as little fond of being reprimanded in public as any other employee. He wants a pat on the back when he has done a good job, and he wants advancement to be on a merit basis, independent of favoritism. The engineer, however, may have a more pronounced sense of dignity and of the significance of his work.

The greatest opportunity for improvement in industrial organizations today lies in the field of improved employer-employee relations. Many employers, however, confuse employer-employee relations with union relations, which are only one narrow phase of the broader problem. They often fail to recognize the employee problem until the union knocks on the door. Then they sometimes become quite vocal about their "ungrateful" employees, and devote their entire attention to union problems, continuing to ignore the employee problem which had been present all the time, and which caused the employees to turn to a union. A case in point is that of foremen's unions. If the history of the foremen's union movement is traced, it will be found that an employee problem existed among foremen long before the foremen turned to unions in an attempt to force higher management to give them an adequate hearing.

RELATION TO MANAGEMENT

The engineer's relation to management is somewhat similar to that of the foreman, although the engineer is, if anything, even closer to management. But it sometimes seems that the higher up in the organization an employee may be, the less some managements recognize his desire to be recognized as an individual.

The only real solution to the union problem is to solve the employee relations problem, and employers, must recognize that fact. Such good employer-employee relations must be developed that the union, if there is one, must remain reasonable or lose the support of the employees themselves. Employees will support a union, no matter how unreasonable it is, as a counter-irritant to management if they feel that management itself is unreasonable.

This does not mean that the mere existence of an engineers' union, or a foremen's union, or any other union in a plant, is evidence of unsatisfactory employee relations. With a strong labor movement, the employees may organize even where relations are good. But, by and large, taking the country as a whole and industry as a whole, unionization never would have gained the ground it has if industry had not left the door wide open—Wagner Act or no Wagner Act.

The door may be opened to unionization by such a simple thing as failure to provide means by which the employee can get attention for his gripes. In the National War Labor Board panel hearings on foremen's unionization, a point emphasized by the union was that there was no grievance machinery, no way in which a foreman could talk over his difficulties with his employer. A simple enough problem, is it not? But all these employee relations problems are fundamentally simple. The road to good employee relations is really nothing more than the road marked "Good Management."

Good management treats people as individuals. It does not, discharge an employee for example, who has been with the company for 30 years because he is old and has passed the peak of usefulness. It finds some other way of taking care of him. But 30-year men still are being discharged unjustly in the United States, and the sad part of it is that many in management see nothing wrong with such actions. Unfortunately those who are

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suffering from bad employee relations frequently think they are doing everything possible for their employees, and that all the trouble occurs merely because the employees are unappreciative.

If management throughout the United States would spend on its employee problem (not the union problem) just five per cent of the time it spends on production and finance, there would be fewer serious employee problems in the country. That means, of course, an effective five per cent. There is no need for more paternalism—buying turkeys for employees and things of that sort, which some people seem to think are the heart of employee relations. The employee is "ungrateful" for paternalism as well he may be, because he does not want it. What he wants is fairness and consideration, a chance to feel that management considers him important. And he wants an opportunity to advance if he has the ability to do so.

EMPLOYEE CAPABILITIES

In the case of the engineer, management has been particularly remiss in providing for advancement. Young college graduates are taken, because they can be hired for $150 a month, and are put on jobs which clerks could do, with no provision for advancement as they gain experience.

Recently I revisited a company after a lapse of five years. Except for the tinges of gray in the hair of some of the men, it seemed that I had been away hardly a month. Everybody had the same job he had held five years before.

I am sure that the man at the reception desk—a man 40 years of age who did nothing but announce callers—was not being used at his highest skill. True, he was not an engineer, but he had a personality which qualified him for something better, possibly as a salesman. It had not occurred to anyone, apparently, to help him out of his rut. Then there was the third assistant engineer, a college graduate. "I've been here for 15 years now," he said, "and I have the same job I had when I came."

Of course, these men could, and probably should, have quit. But the employer, if he wants good employee relations, never should make this necessary. If he hires these men he should find a way to develop them to their maximum capabilities. No man can be happy on his job unless he feels that he is being used at his highest skill. Any less significant work spells frustration.

Along with better opportunities for the engineering group, there is a need for more exact placement; and for that more accurate job descriptions are a necessity. Accurate job descriptions made it possible for one large manufacturing company to hire men who had failed in engineering school after the first or second year for positions which ordinarily would have appeared to require graduate engineers. The men with a year or two of training, it was discovered, were perfectly capable of handling work which required a smattering of engineering knowledge. What is more, they were satisfied with positions where graduate engineers could not have been satisfied for very long. In terms of human values, a man of active intelligence tied to a monotonously repetitive job is likely to be much more dissatisfied than an unqualified man on a difficult job.

In addition, job descriptions form the basis of a proper rate structure, and a poorly designed rate structure is one of the great sources of employee dissatisfaction. Even more important than the general level of rates are the relative rates within the structures. Conditions can be reasonably satisfactory where rates are low if individuals are classified properly with respect to each other, but there can be great dissatisfaction even with high rates, where individual salaries do not bear a proper relationship. The rates must be aligned in such a way that no one can say justifiably, "I have a more important job than so-and-so but he is paid more money than I."

Lately there has been a great deal of discussion about whether engineers are part of management or not. Actually, of course, they generally are, or should be. However, sometimes they are not treated so, just as foremen frequently are not. Whether they are or not, the National Labor Relations Board long since has decided that they come under the provisions of the Wagner Act. Whether or not the employer wants his engineers to organize, the most constructive approach is to build sound employee relations so that his engineers feel no need of organization.

Of course, from the viewpoint of the engineers themselves, another question arises: Should they organize as a matter of self-protection? Will it be to their advantage?

Engineers, by the very nature of their work, must operate on the basis of individual merit, and certainly there is nothing in union theory that recognizes individual merit. If engineers are tempted to bargain collectively they are bound to lose an important element of their professional status. As a professional man, the engineer should be able to accomplish more by individual bargaining, because collective bargaining tends to reduce everyone to the average. Collective bargaining frequently is involved with questions of *average* wage and *minimum* wage; with little concern for recognition of unusual merit or ability. Those who are below average benefit, of course, but what engineer is willing to put himself in that category? If he is, he is probably in the wrong field.

Even if the engineers themselves do not want to organize, there is the possibility that they may be included within the scope of the production workers' union. This could occur if the National Labor Relations Board designates the entire plant as the voting unit. As engineers are a comparatively small group numerically, they easily could be outvoted, and the productive

workers' union might become the collective bargaining agent for their group.

The best way to avoid such a situation is for the engineers to request that they be excluded from the collective bargaining unit of production employees, because of the absence of "mutuality of interest." The National Labor Relations Board usually would recognize such a request under the so-called "Globe Doctrine." The production workers' union probably would not be too interested in the engineers' affairs, as they normally constitute only a small proportion of the membership. If excluded from the production workers' unit, the engineers either can form their own collective bargaining agency, or continue to discuss their problems individually with their superiors. Only in a closed shop or in a union shop in a collective bargaining unit including the engineers, are the engineers forced to belong to the union in order to keep their jobs. An engineer in that position no doubt would become active in the union, and attempt to see that the viewpoint of his group received consideration.

THE ENGINEER AS AN ENGINEER

As for the engineer as engineer, the technical training given is, in general, excellent. As Dean Kimball of Cornell University used to say: "The average engineer who gets out of our engineering schools can figure out most any kind of a problem and be pretty sure of the answer, except possibly where the decimal point is." In dealing with the problems that can be solved on a slide rule, the engineer is, for the most part, entirely competent; but his training has been a narrow one, and that fact has handicapped him in some of the broader aspects of his work.

Doctor G. F. Kuder, who has done a great deal with interest tests, finds that engineers tend to score high in interest in mechanical and scientific fields, and very low in those involving persuasive tendencies and interest in social service. This is to be expected in view of the fact that engineering training, particularly during the last 20 years, has emphasized technical knowledge at the expense of other qualities. One of the main reasons manufacturers have developed graduate training courses has been that the young engineering graduate has had many rough corners to knock off and has needed to become accustomed to rubbing shoulders with other people.

The outstanding cause, in my opinion, is the failure of the engineering schools to provide training in human relations. Not only by taste, but by training, the engineer usually is rather on the introvert side. He tends to be satisfied to retire from the public eye and concentrate on physical things, rather than on the human beings about him. Generally he dislikes a sales job, and it is amazing what he sometimes does in the way of human relations. The average engineering manager often has trouble with his men because he knows how to handle only the mechanical aspects of his work; nothing in his training has fitted him for the handling of men.

One large manufacturer used to tell young engineering graduates attending his training course: "We know you won't like some of the things we are going to give you in this course. You won't like it because you are engineers. But we are engineers too, and we have gone through it. We know you don't know how to talk, how to persuade anybody to do anything, and so we're going, first of all, to give you a course in public speaking." At that the students would groan.

"Then," the leaders of the program would say, "we're going to teach you how to write." More groans.

"Then," continuing, "we're going to give you a basic course in selling."

"But," the students always protested, "We don't have to sell. We're going to be engineers."

It would be pointed out to them that an engineer needs to know how to sell his designs and his ideas to his own superiors if to no others, that he even has to sell the shop people if he wants them to work with him wholeheartedly and produce the best results and eventually the students would become convinced that there might be something to the program.

During a period of years as an engineering manager, I have observed that many engineers are not as commercially minded as they should be. Design engineers frequently are interested more in making a theoretically perfect design than they are in producing something that will sell at a profit.

It was B. G. Lamme who said, "The test of a good engineer is whether or not he can drop the subject when he gets a design that is good enough." And everyone has seen engineers who are unable to do just that. They want perfection, even if the last ounce of excellence costs ten per cent and is not worth five cents more.

Another quality which seems to be lacking among our engineers, and which may be even more difficult to develop, is the ability to state problems. Most engineers can solve a problem if it is stated for them, but they cannot seem to isolate the problem themselves. The employer has to state the problem for them, which means that they are a good deal less valuable to him than they could be. In many cases, once the problem itself is clear, the solution is apparent, or at least easily obtainable through ordinary engineering techniques.

As has been indicated, some of these gaps in the engineers' background are filled in with postgraduate courses given by industry. However, the colleges should do more of that work. They should be able to do it more thoroughly than industry can; and, as a matter of fact, some of them are beginning to accept responsibility for it. Cornell University, for example, just has added another year to its engineering course, 20 per cent of the subjects to be so-called "cultural" subjects—such as English, public speaking, economics, and business law. Engineers need these subjects, and they need also

some knowledge of accounting principles, of executive techniques, and of the fundamental principles of handling people.*

ENGINEERS AS MANAGEMENT

Finally, there is the last phase of the subject, engineers as candidates for managerial positions. Engineering training is, in my opinion, the best preparation that we have today for managerial work, particularly in fields like manufacturing, utility operation, and others of a comparatively technical nature. However, the gaps in that training which handicap the engineer in his job as an engineer are doubly hampering to him in a managerial position.

The more the job becomes one requiring executive ability, the less there is need of a slide rule. The more general the problems become, the more what is going on in the world has a bearing on the decisions. The head of a company is concerned with labor problems, the tariff, the Export-Import Bank—basic questions much broader than any covered in ordinary engineering courses. Thus, it seems to me, we could broaden appreciably the training in the case of the engineers to be developed for management positions. Here again much more emphasis on the human element is needed. Executive decisions today must be based on more than pure logic, for it is often pure emotion which determines the effect of a decision on employees.

EMPLOYEE REACTION

As an illustration of how deficient the engineer may be in this respect a recent case may be cited. Some executives were discussing the employee dissatisfaction in their plant. (It is not unionized—yet.)

The manager of the company remarked, "You know, I cannot understand these employees. It seems that the more you do for them, the more dissatisfaction you create. We instituted a pension plan for the employees that entails absolutely no cost to them and yet they are dissatisfied."

"What kind of a plan is it?" I asked.

"Well, employees earning more than $5,000 receive ten per cent of their monthly salary as a monthly pension after they reach the age of 65."

"What about those earning under $5,000?"

"They receive five per cent."

"Do I understand you correctly? Those earning over $5000 get a larger percentage than those under $5,000?"

"Yes."

"Are you surprised that you have dissatisfaction?"

"Well," he said, "it doesn't cost them anything; we give it to them."

The reaction of the employees easily can be imagined. Many of them were threatening to quit the company, would have done so, in fact, if the plant had not been in an isolated spot where other jobs were not obtainable.

It is incidents such as this, elementary things, which can play havoc with human relations. Probably even pure logic should have enabled management to forecast the employee reaction in that case, but the executives went blithely on their way, spending something like a million dollars to establish the plan. The money, of course, was thrown out the window, so far as developing good employee relations was concerned.

I believe that there is a great future ahead for engineers, if the gaps in engineering education and training can be filled in and they learn to handle the human aspects of their jobs as skillfully as they handle the technical phases. Industry is entering a new period, a period in which human problems are going to be even more important than technical problems. "Handling labor relations" is merely calling in the fire department. What is needed is fire prevention; employer-employee relations must be handled in such a way that there is no need for some outside organization to come in and speak for the employees. If engineers are going to take their place in a broader field, they must learn to recognize the human relations aspects of management, instead of leaving that important phase to some other professional group.

* See *Mechanical Engineering*, May, June, and July 1944, for a series of articles by W. J. King on the nontechnical knowledge needed by engineers.

Electrical Experiments in Germany

According to a recent report published by the British Intelligence Objectives Subcommittee, 550 yards of experimental 400-kv a-c line had been constructed in order to study corona loss in connection with a proposed 480-mile transmission of 600,000 kva from the Alps to Cologne. Tests showed that an arrangement of four conductors in parallel for each phase with 10-inch spacing between the steel-cored aluminium conductors would provide the maximum current-carrying capacity with the minimum of corona loss. Single-phase transformers with a 400-kv bushing out of one end and a 220-kv bushing for connection to a Petersen coil at the other, with lower voltage bushings at both ends, were to have been used. The air-blast circuit-breakers to be installed, rated at 1,000 amperes and 6,500 megavolt-amperes interrupting capacity, had 14 breaks in series with capacitors for promoting equal voltage distribution between breaks.

Experiments also were performed with d-c transmission with the ultimate idea of obtaining power from Norway and further supplies from the Alps. Tests were successful enough to warrant planning transmission of 160,000 kw by means of two 400-kv d-c lines from a station on the Elbe to the Marienfeld station in Berlin, 100 miles away.

Conservation in the Power Industry

N. E. FUNK
FELLOW AIEE

In the score of years since 1925, the expansion of the electric utility industry has been accompanied by deliberate and sustained reductions in fuel used and in the amounts of materials required to manufacture its equipment. Efficiency of operation with higher temperatures and greater pressures has provided the first saving, and improvement in design and interconnection of systems, the second. However, the author adds, the fuel economy curve is flattening out, and the time is ripe for a new point of attack of the problem.

THOUGH THIS article has been confined chiefly to power generation, it should be stated at the outset that all phases of the power industry have contributed to the conservation of natural resources. The privately owned utilities over a long period of time have met the combined challenges of competition, restrictive legislation, and, of late, the common woes of the war years, and have been able continually to increase their efficiency of production.

The accomplishments throughout the industry over the past two decades, resulting in conservation of fuels and of other essential materials, have been made possible by a number of basic developments, namely:

1. Greatly improved efficiency in steam power plants.
2. Rehabilitation of existing stations and equipment.
3. Interconnection of large systems.
4. Installation of hydroelectric plants where they were justified economically.

Statistics, as such, can be dry and burdensome, but a few rounded-out figures, can be used to span the attainments of the industry over the period to be considered.

At the end of 1925, the total installed generating capacity in the United States for public supply amounted to 23,000,000 kw, with an output in that year of 65,000,000,000 kilowatt-hours. Of the latter, about 22,000,000,000 kilowatt-hours (34 per cent) were generated by water power. At the beginning of 1945, the generating capacity exceeded 50,000,000 kw, with a yearly output during 1944 of 230,000,000,000 kilowatt-hours. Of the 1944 output, about 74,000,000,000 kilowatt-hours (32 per cent) were produced by hydraulic power. Distribution of the installed capacity of 50,000,000 kw showed less than 20 per cent being operated and controlled by the various government agencies, most of which was in hydraulic plants.

In 1925 a national average of 2.1 pounds of coal was required to produce a kilowatt-hour of electricity in steam generating power plants. For the year 1944 this national average had been reduced to 1.3 pounds per kilowatt-hour, and there were numerous plants built in the last decade which were producing a kilowatt-hour for less than a pound of coal—some even as low as 0.85 pound. The averages reflect the equivalent in coal, in coke, fuel oils, and gas where such fuels were utilized. Expressing this saving in another manner: it required 62 per cent more fuel to produce a kilowatt-hour of electric energy in 1925, than it did in 1944. Further, had the energy produced by steam power in 1944 been made at the coal rate of 1925, there would have been an increase in the amount of fuel burned of more than 62,000,000 tons. This information presents the picture of the size, growth, and improved fuel economy of the electrical utility industry.

Developments in power plant equipment and improvements in performance have been due to the co-operative efforts of equipment manufacturers and the engineers of the operating companies. The ever-increasing demands of the utility companies' engineers and operators for greater reliability, increased capacity, and improved performance arise from the knowledge gained through past performance of equipment tested in the laboratory of actual operating experience. Many improvements have come directly in this way, and the engineers of operating properties have had a major part in their development.

Special joint research programs between utility companies and manufacturers have been conducted from time to time under actual operating conditions in the utilities' plants, at a material saving of time and money. For example, where large quantities of high-pressure high-temperature steam are necessary to the experiments, the utility can provide the live steam and absorb the exhaust steam and the electric energy produced. Such research is encouraged and proves of mutual benefit to the utility, the manufacturer, and the customers of both. An illustration of such joint research is the tests carried out on a special superposed turbine built by Westinghouse Electric Corporation and installed at

Essential substance of an address presented at the general luncheon held May 2, 1946, during the 34th annual meeting of the Chamber of Commerce of the United States in Atlantic City, N. J. The subject for the luncheon was "Our 'Vanishing' Natural Resources."

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Schuylkill station of the Philadelphia Electric Company. The unit, of 10,000-kw capacity with a full-size impulse wheel, operating at 1,250 pounds pressure and 900 degrees Fahrenheit, was utilized for study of factors affecting performance of impulse blading under actual plant conditions. The results of these tests produced new information which already has been utilized in eliminating some difficulties with the blading of existing machines, and which, without question, has resulted in the ability to improve future designs.

No small part has been played by the work of committees of the national engineering societies, including the AIEE, the American Society of Mechanical Engineers, the American Society for Testing Materials, the American Standards Association; and of outstanding industry committees, namely, the electrical equipment, hydraulic power, and prime movers committees of the old National Electric Light Association, and, in more recent years, of the Edison Electric Institute and the committee on power generation of the Association of Edison Illuminating Companies. Through reports of operating performance and round table discussions between committee members and manufacturers, the time for proving new designs has been reduced considerably, and has increased greatly the rate at which each new step forward can be taken with confidence.

The accomplishments throughout the industry in the past two decades toward conservation of fuel and other materials have been made possible by a number of particularly outstanding basic developments. Of primary importance has been the ability to increase steam pressures and temperatures markedly and to increase the speed of rotating machinery. The first has been responsible for the improvement in efficiency, and both have reduced greatly the weight of materials required. Both also have necessitated a tremendous improvement in the quality of material used.

In 1925 thought had been given to increasing turbine speeds with greater unit outputs per pound of material, and one installation had gone into service at 1,200 pounds per square inch pressure and a temperature of 700 degrees Fahrenheit, but, because of lack of experience with these steam conditions, pressure of 400 pounds per square inch and temperatures of 700 degrees Fahrenheit were considered more desirable at the time.

METALLURGICAL RESEARCH

Since that time, continued studies of performance of metals for use at higher steam temperatures and pressures have produced alloy materials suitable for temperatures from 900 to 950 degrees Fahrenheit. In fact, a few installations have been designed for operating temperatures of 1,000 to 1,050 degrees Fahrenheit. One unit is operating at a nominal pressure of 2,300 pounds per square inch. It is of interest to note in passing that at 900 degrees Fahrenheit and above piping and equipment will have a dull red glow in the dark.

Utilization of these elevated steam conditions has been progressive. Trends may be arranged in two general classifications. Prior to 1930, the marked change was an increase in steam pressure in boilers and turbines. Temperatures were increased, but not to the range of today. The maximum temperature for this first step was in the vicinity of 825 degrees Fahrenheit. During the period from 1925 to 1936 turbine capacities for these higher pressure units were comparatively small. The higher pressures thereafter were accepted, and steam temperatures showed a gradually rising trend from about 1939 on—the second step. Subsequent installations revealed a steady increase in capacities of turbines with the higher steam temperatures.

Advancement in the art of welding is a most necessary adjunct, since elevated pressure and temperatures have required the elimination of bolted, flanged joints wherever possible from the point of view of safety and economy. Welding processes have been developed to such an extent that most of the piping and most of the equipment in present-day plants may be welded most economically.

PLANT REHABILITATION

With the availability of new materials, thermodynamic research opened another major field of improvement. Many existing plants had been installed and were operating at pressures from 200 to 400 pounds per square inch and temperatures from about 500 to 700 degrees Fahrenheit. By installing high pressure boilers and turbine the exhaust steam from the latter could be utilized to drive the older turbines through existing steam piping kept practically intact. Installation of the new equipment, designed for operation at from 1,200 to 1,800 pounds per square inch pressure and 900–950 degrees Fahrenheit steam temperature resulted in rejuvenation of the older plant. The existing plant thereby was improved in efficiency, to an extent that permitted it to approach the economy of a new plant operating at the higher temperature and pressure. No new condensing equipment nor increase in circulating water were required with the additional capacity. Installation of the superposed turbine was an important factor in the postponing of obsolescence of low-pressure equipment and conserving material.

3,600 RPM TURBINE GENERATORS—HYDROGEN COOLING

In order to prevent operating difficulties from distortion and expansion, it was found desirable to reduce to a minimum the amount of material in contact with high-pressure and high-temperature steam. This called for turbine speeds of 3,600 rpm rather than 1,800 rpm generating units, which were the general practice for the power pressure range. Here again metallurgy was called upon, not for high-temperature metals, but for higher strength materials to withstand the forces de-

veloped in high-speed rotating parts. The larger 3,600 rpm machines are less than ten years old, and in addition to their lower cost, they are, in general, more efficient and use less material. Contributing to this latter feature is the use of hydrogen, a less dense gas, rather than air for cooling the generator. With hydrogen cooling, the rating of the machine can be increased about 20 per cent for a given amount of active material. The life of the winding insulation is increased as a result of the absence of moisture, oxygen, and dirt, and possibilities of damage to windings from other causes are reduced. A few cross compound hydrogen-cooled machines of 100,000-kw capacity, 1,250 pounds per square inch with 950 degrees Fahrenheit steam, have been in commercial operation at 3,600 rpm for several years.

STEAM GENERATING UNITS

Substantial changes have taken place in the design of boilers and allied equipment. Units for large outputs generally have been accepted, some in capacities as high as 1,000,000 pounds per hour evaporation. Boilers of 500,000 to 600,000 pounds per hour output are considered commonplace. Most of the larger boilers are pulverized coal fired. An attempt also has been made to design these units for adaptability to varying classifications of fuels. The use of alternate fuels also has been considered with favor. The latter item was brought to prominence during the year 1939 when a coal strike was in effect. The ready adaptability to oil or gas was quite advantageous. In other instances, although the units are not equipped with alternate burning devices, conversion possibilities were allowed for in their design.

Steam generating units of today bear no resemblance whatever to the boiler of 1925. Furnaces are universally water-cooled. Economizers and air preheaters have been added, whereas previously they usually were omitted. The superheater producing the high steam temperature has replaced some of the low-temperature heating surface, and, while the physical size of the unit has increased tremendously, the actual material per thousand pounds of steam produced has undergone a compensatory decrease. These changes in design also have increased the efficiency of steam production, so that now more energy in a fuel is converted to heat energy in the steam than was the case in the equipment of 1925.

INTERCONNECTION

Interconnection between systems by reducing the reserve capacity required, taking advantage of diversity, and permitting the operation of the most efficient plants in all systems for a greater number of hours has contributed not only to the safety of the systems so connected, but also to a noteworthy saving in fuel consumed. Interconnection permits each system to utilize with safety larger units than would be desirable with individual operation, and this, together with the saving of reserve capacity, likewise has been beneficial in conserving the raw materials which go into the building of a plant.

HYDROELECTRIC INSTALLATIONS

Where it has been economically feasible, the electrical utilities have installed hydroelectric plants to supply part of their power, and thus have contributed to the conservation of the nation's fuel supply. In 1925 the privately owned hydroelectric capacity was 5,600,000 kw, and in 1944 it was 8,800,000—an increase of 3,200,000 kw. In the meantime, the publicly owned hydroelectric plants, which had a capacity of 600,000 kw in 1925, increased 5,200,000 kw in capacity to 5,800,000 kw. As a further comparison, in the year 1944 the total energy produced in privately owned hydroelectric plants was 41,000,000,000 kilowatt-hours, and that produced in publicly owned plants 33,000,000,000 kilowatt-hours. This indicates that the electrical utility industry has not been remiss in utilizing hydroelectric energy where it was beneficial to the customers supplied.

HOW THE PUBLIC BENEFITS

A complete discussion of all improvements in power supply would be beyond the scope of this presentation. The foregoing outlines some of the major accomplishments in generation over the past era.

At the risk of repetition it can be stated that improvements in steam plant economy have conserved large quantities of fuel, and, together with centralized production permitting the use of larger units, have been responsible for the conservation of other natural resources of the country.

The power industry is ever alert in sponsoring and adopting sound improvements, and its facilities continually are being developed to meet any demands that may be imposed.

The fuel economy curve however is flattening out rapidly. With today's available heat cycles, further reduction in fuel consumption becomes increasingly difficult. Some other strategic point of attack may appear practicable later, such as direct conversion, in some manner, of heat energy in the fuel to electric energy. The adaptation of atomic energy, as it is now known, to commercial power production may be realized economically some time in the future, but the development stage for this process no doubt will be long and tedious, assuming it is found to be applicable to our ever-increasing requirements.

The result of all this activity since 1925 has been a steadily decreasing unit cost of electricity to the consumer (about 60 per cent of the 1925 cost) while in the meantime the cost of living index for the United States from the United States Bureau of Labor Statistics shows, despite a drop in the 30's, that during 1944 it was practically equal to that of 1925.

INSTITUTE ACTIVITIES

Pacific Coast Convention, Seattle, Wash., August 27–30, 1946

The Pacific Coast convention will be held in Seattle, Wash., August 27–30, 1946, with headquarters in the Olympic Hotel. Arrangements are being made for a full postwar program of eight sessions, including a session which affords an opportunity for discussion on organization of the engineering profession; entertainment; sports; and inspection trips in a picturesque part of the Pacific Northwest. For the women there will be scenic boat rides and automobile sightseeing tours to the various points of interest about the city. The need to make hotel reservations early is stressed, as explained further under the heading, hotel reservations.

ENTERTAINMENT

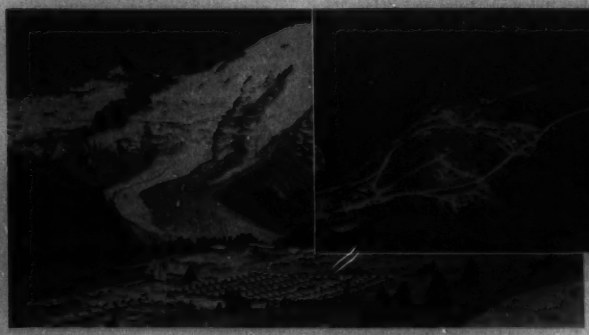
The major entertainment event will be the reception and banquet on Thursday evening. The reception will be held in the foyer outside of the Spanish Ballroom and will be followed immediately by the banquet. One feature of the banquet will be the presentation of the golf prizes from the tournament played the day before.

A theater party is planned for Wednesday evening at the Penthouse Theater. This is a theater at the University of Washington staffed entirely by students in the School of Dramatics.

Entertainment is being planned for the women who are registered at the convention. There will be scenic boat rides and automobile sightseeing tours to the various points of interest about the city. The floating bridge across Lake Washington will be of interest to many.

Sunrise Valley (below) in Mount Rainier National Park is on the route to Yakima, Wash.

(Above) Lake Washington Floating Bridge at Seattle is a four lane highway one and one quarter miles long



(Above) Alder Dam and power plant on the Nisqually River are operated by the Light Department of the City of Tacoma

Schedule of Events

All sessions to be held in the Olympic Bowl at the Olympic Hotel

Tuesday, August 27
8:00 a.m. Registration
10:00 a.m. Opening session
2:00 p.m. Central stations session

Wednesday, August 28
9:00 a.m. Industrial and railroad session
1:00 p.m. Golf tournament for the John B. Fisken Cup
2:00 p.m. Student papers session
8:00 p.m. Theater party

Thursday, August 29
9:00 a.m. Aviation session
2:00 p.m. Power systems session
7:00 p.m. Reception and banquet

Friday, August 30
9:00 a.m. Discussion on organization of the engineering profession
2:00 p.m. Communication

GOLF

The golf tournament will be held on Wednesday at the Inglewood Golf and Country Club. The tournament competition will be medal play on handicap in foursomes for the John B. Fisken Cup and other prizes.

INSPECTION TRIPS

There will be inspection trips during the convention and on Saturday, August 31. The trips in the city will include Boeing Aircraft Company, where the wind tunnel is of particular interest. The various substations of the Puget Sound Power and Light Company and the Seattle City Light Department will be visited. The University of Washington and various industrial plants, including lumber and plywood plants, will be inspected.

Out-of-town trips will include the Puget Sound Navy Yard at Bremerton and lumber and pulp mills at Everett. The Snoqualmie River hydroelectric plant of the Puget Sound Power and Light Company and the Nisqually River plant of the Tacoma City Light Department are nearby. Mount Rainier National Park is also within a few hours' drive of Seattle. The large Government power plants at Grand Coulee Dam near Spokane and at Bonneville Dam near Portland may be visited on the way to or from the convention. Victoria and Vancouver, British Columbia, in Canada may be reached by boat, rail, or car from Seattle.

HOTEL RESERVATIONS

Because of the limited space available at the Olympic Hotel, convention headquarters, and the overcrowding of all hotels in the city, members should make hotel reservations immediately. The committee has reserved 200 rooms (doubles, with twin beds only available); rates, $6, $7, $8, and $10 for two people, or from $3 to $5 per person. The committee cannot be assured of any single rooms. Please make reservations for the Olympic by writing to C. H. Cutter, chairman, hotel and registration committee, 814 Securities Building, Seattle 1, Wash., stating the price of room preferred and with whom you will share the room, as well as the time and date of arrival and departure. Reservations at other hotels should be made by writing directly to the hotel preferred.

ADVANCE REGISTRATION

Members of Districts 6, 8, and 9 and the Vancouver Section who will attend the convention should register in advance by filling in and mailing the advance registration card, which will be sent to them the first week in August. All others should register by writing to C. H. Cutter, chairman, hotel and registration committee, 814 Securities Building, Seattle 1, Wash. A registration fee of $2 will be charged all nonmembers except Student members and the immediate families of members.

COMMITTEES

Pacific Coast convention committee members are:

J. Hellenthal, *general chairman;* H. M. Gustafson, *vice-chairman;* H. R. Brown, *secretary;* G. M. Palo, *treasurer;* D. I. Anzini, C. B. Carpenter, E. S. Condon, O. A. Demuth, F. F. Evenson, J. P. Fraser, F. E. Gardiner, J. F. Gogins, L. D. Harris, E. A. Loew, F. O. McMillan, R. R. Richey, C. A. Rollins, W. C. Smith, C. F. Terrell.

Subcommittee chairmen are:

L. B. Robinson, *program;* E. B. Hansen, *finance;* C. H. Cutter, *hotel and registration;* R. E. Kistler, *publicity;* R. E. Lindblom, *student activities;* R. A. Walker, *transportation and trips;* C. R. Kingsbury, *golf;* H. R. Loew, *entertainment;* Mrs. C. S. Alger, *ladies' entertainment.*

Officers for 1946–47 Announced at Annual Meeting

Institute officers for the year commencing August 1, 1946, were announced in the report made by the committee of tellers to the annual meeting of the AIEE held in Detroit, Mich., June 26. The new officers are:

President: J. Elmer Housley, district power manager, Aluminum Company of America, Alcoa, Tenn.

Vice-Presidents: E. W. Davis, chief electrical engineer, Simplex Wire and Cable Company, Cambridge, Mass. (District 1, North Eastern); O. E. Buckley, president, Bell Telephone Laboratories, Inc., New York, N. Y. (District 3, New York City); T. G. LeClair, staff engineer, Commonwealth Edison Company, Chicago, Ill. (District 5, Great Lakes); R. F. Danner, general superintendent, Oklahoma Gas and Electric Company, Oklahoma City (District 7, South West); C. F. Terrell, vice-president, Puget Sound Power and Light Company, Seattle, Wash. (District 9, North West).

Directors: J. F. Fairman, vice-president in charge of production, Consolidated Edison Company of New York (N. Y.), Inc.; R. T. Henry, chief electrical engineer, engineering department, Buffalo (N. Y.), Niagara, and Eastern Power Company; E. P. Yerkes, engineer of equipment and buildings, eastern area, Bell Telephone Company of Pennsylvania, Philadelphia.

Treasurer: W. I. Slichter, professor emeritus of electrical engineering, Columbia University, New York, N. Y.

The board of directors for the administrative year commencing August 1, 1946, will consist of the foregoing elected officers and the following holdover officers:

William E. Wickenden, Cleveland, Ohio (retiring president); Charles A. Powel, East Pittsburgh, Pa. (junior past president); F. F. Evenson, San Diego, Calif.; E. S. Fields, Cincinnati, Ohio; F. L. Lawton, Montréal, Quebec, Canada; L. M. Robertson, Denver Colo.; H. B. Wolf, Charlotte, N. C. (*vice-presidents*); P. L. Alger, Schenectady, N. Y.; J. M. Flanigen, Atlanta, Ga.; G. M. Laffoon, East Pittsburgh, Pa.; M. J. McHenry, Toronto, Ontario, Canada; C. W. Mier, Dallas, Tex.; S. H. Mortensen, Milwaukee, Wis.; J. R. North, Jackson, Mich.; D. A. Quarles, New York, N. Y.; Walter C. Smith, San Francisco, Calif. (*directors*).

1946 Lamme Medal Nominations Due December 1

Special attention is directed to the fact that the names of Institute members who are considered eligible for the AIEE Lamme Medal, to be awarded early in 1947, may be submitted by any member in accordance with section 1 of article VI of the bylaws of the Lamme Medal committee, as follows:

The committee shall cause to be published in one or more issues of *Electrical Engineering*, or of its successors, each year, preferably including the June issue, a statement regarding the Lamme Medal and an invitation for any member to present to the secretary of the Institute by December 1, the name of a member as a nominee for the medal, accompanied by a statement of his "meritorious achievement" and the names of at least three engineers of standing who are familiar with the achievement.

Each nomination should give concisely the specific grounds upon which the award is proposed, and also a complete detailed statement of the achievements of the nominee, to enable the committee to determine its significance as compared with the achievements of other nominees. If the work of the nominee has been of a somewhat general character in co-operation with others, specific information should be given regarding his individual contributions. Names of endorsers should be given as specified in the foregoing quotation.

June Supplement in Preparation. Discussions which have been submitted on the technical papers published in the January–June monthly Transactions sections of *Electrical Engineering* will appear in the June 1946 "Supplement to Electrical Engineering—Transactions Section" soon to be released. This will complete the publication of papers and discussions presented at the New York winter convention, all of which will be in the 1946 *Transactions* volume.

Future AIEE Meetings

Pacific Coast Convention
Seattle, Wash., August 27–30, 1946

Great Lakes District Meeting
Fort Wayne, Ind., September 25–27, 1946

Report of the Board of Directors

THE BOARD OF DIRECTORS of the American Institute of Electrical Engineers presents herewith to the membership its 62nd annual report, for the fiscal year ending April 30, 1946. It includes a general balance sheet and other statements, showing the financial condition of the Institute at the close of the fiscal year, and a brief summary of the principal activities of the Institute during the year, more detailed information having been published from month to month in *Electrical Engineering*.

BOARD OF DIRECTORS' MEETING

Five meetings of the board of directors were held during the year, four in New York, N. Y., and one in Cleveland, Ohio. Four meetings of the executive committee were held.

Information regarding many of the more important activities of the Institute which have been under consideration by the board of directors and AIFE committees is published each month in the section of *Electrical Engineering* devoted to Institute activities.

PLACES VISITED BY PRESIDENT WICKENDEN

California
Los Angeles Section; San Diego Section
San Francisco Section
University of California Branch, Berkeley

Canada
Montreal Section; Toronto Section
Vancouver Section

Colorado
Denver Section
University of Colorado Branch, Boulder

Connecticut
Connecticut Section, New Haven
University of Connecticut Branch, Storrs

District of Columbia
Washington Section

Florida
Florida Section, Miami
University of Florida Branch, Gainesville

Georgia
Georgia Section, Atlanta

Idaho
University of Idaho Branch, Moscow

Illinois
Chicago Section; Illinois Valley Section, Peoria

Indiana
Central Indiana Section, Indianapolis
Fort Wayne Section

Massachusetts
Joint meeting in Boston of Boston, Lynn, Providence, and Worcester Sections
Northeastern University Branch, Boston
Pittsfield Section; Springfield Section

Michigan
Michigan Section, Detroit
Summer Convention, Detroit

Missouri
Kansas City Section
St. Louis Section

New York
New York Section, Nutley, N. J.
North Eastern District Meeting, Buffalo
Winter Convention, New York

North Carolina
North Carolina Section, Raleigh
Southern District Meeting, Asheville

Ohio
Cincinnati Section; Cleveland Section
Dayton Section

Oregon
Portland Section

Pennsylvania
Philadelphia Section
Pittsburgh Section

South Carolina
South Carolina Section, Columbia

Texas
South West District Meeting, San Antonio

Utah
Utah Section, Salt Lake City

Virginia
Virginia Section, Richmond

Washington
Seattle Section
Spokane Section
State College of Washington Branch, Pullman

ANNUAL MEETING

On account of the cancellation of the regular summer convention, the annual meeting of the AIEE was held in the Engineering Societies Building, New York, June 27, 1945. The annual report of the board of directors for the fiscal year which ended April 30, 1945, was presented in abstract by the secretary, and the treasurer's report was presented by W. I. Slichter. Reports of the committee of tellers on votes for officers for the year to begin on August 1, 1945, and for the proposed amendments to the constitution were presented.

President-Elect Wickenden responded to his introduction with a brief address. Awards of Institute prizes were reported and presentations made to the winners. The election of Doctor C. E. Skinner as an honorary member was announced. The Lamme Medal was presented to Doctor S. H. Mortensen. The meeting was concluded with a brief review of Institute activities during the year by C. A. Powel, president.

WINTER CONVENTION

The 34th winter convention was held in New York, January 21–25, 1946, with a registration of 2,624, an all-time record. The program included 17 technical sessions, 8 conferences, and 3 symposiums, at which 78 technical and 24 conference papers were presented, a conference on Institute activities, a general session, and a joint evening session with the Institute of Radio Engineers. Other events were a dinner-dance; smoker; women's luncheon, bridge, and fashion show; and inspection trips.

In the general session, the Edison Medal was presented to Philip Sporn, executive vice-president, American Gas and Electric Service Corporation, New York, and an address on "Development of Atomic Energy" was delivered by Doctor J. R. Dunning, director of the division of war research, Columbia University, New York, and technical adviser, The Kellex Corporation.

The joint session with the IRE on Wednesday evening was devoted to the presentation of the Hoover Medal to Doctor W. H. Harrison, vice-president, American Telephone and Telegraph Company, New York, and an address on "Some Electrical Engineering and General Aspects of the Atomic Bomb Project" by Major General Leslie R. Groves.

DISTRICT MEETINGS

South West District Meeting. This meeting was held in San Antonio, Tex., April 16–18, 1946, with a registration of 366. The principal sessions included 5 technical, one on electrical problems in Mexico, one general, one for student papers, and one for a general discussion of Institute activities. Other events were a banquet, smoker, inspection trip to Randolph Field, luncheon meeting of the District executive committee, and luncheon meeting of the Student Branch counselors.

North Eastern District Meeting. Held in Buffalo, N. Y., April 24–26, 1946, this meeting had been postponed, on account of wartime travel congestion, from the spring of 1945. The registration was about 400. The chief activities were 8 technical sessions, a conference on quality control, a general luncheon, a banquet, a dinner and smoker, a student technical session, a District executive committee luncheon, a Branch counselors' and chairmen's luncheon, inspection trips, a women's luncheon, and a visit to Niagara Falls and dinner for women.

COMMITTEE ON COLLECTIVE BARGAINING AND RELATED MATTERS

The committee's tentative report was published in the July 1945 issue of *Electrical Engineering*, and this report was given publicity by several of the other engineering societies by publication, or by mailings, to members. Also, in December 1945, the AIEE Sections committee mailed copies of the report to all AIEE Section chairmen suggesting discussions of it at Section meetings. The chairman and the secretary of the committee on collective bargaining and related matters have talked on this subject at several AIEE Section meetings. In all of these efforts at giving publicity to the tentative report, members have been urged to read the report and to send in comments and criticisms. To date less than 50 such comments have been received by the committee.

The interest in the subject, particularly on the part of younger engineers, continues at high level, but manifests itself in the form of inquiries pertaining to specific cases of attempts to place engineers in bargaining groups not of their own choosing, rather than in comments on the committee's tentative report.

The preparation of a manual on the subject of collective bargaining, as it relates to professional employees, has been followed actively by the committee and its consultant, Doctor Waldo Fisher, during the past year. Several chapters have been written and have been reviewed by the committee. To carry out this work, two two-day meetings of the committee with its consultant were held, one in September 1945 and the other in January 1946. Another such two-day meeting is scheduled for May or June

1946. It is expected that the drafting of the manual will be completed during the fall of 1946.

The AIEE committee on collective bargaining and related matters is collaborating with the committee on collective bargaining under the committee on the economic status of the engineer (Engineers Joint Council), and it is expected that the final wording and arrangement of the manual will have the approval of the committee on the economic status of the engineer. Such approval, it is hoped, will lead to joint publication of the manual by the several engineering societies participating in the work of the committee on the economic status of the engineer.

The committee has under consideration the mailing of a questionnaire to all members to obtain their views on the matter of collective bargaining by professional employees, and on federal legislation affecting such collective bargaining. The committee is hopeful that such a questionnaire might be handled through the committee on the economic status of the engineer, and go to the combined membership of the engineering societies participating in the work of the latter committee.

COMMITTEE ON REGISTRATION OF ENGINEERS

On August 28, 1945, the conference committee on Model Law met to consider revisions of definitions. A report on the actions of the meeting was published in *Electrical Engineering* for May 1946, in connection with the complete text of the Model Law.

This revision was discussed by the American Society of Civil Engineers' committee on registration of engineers at its meeting in January 1945, at which time the revision of the second paragraph of Section 13 was recommended as quoted.

The AIEE was invited to endorse the new draft. At the January 25th meeting of the AIEE board of directors, the following resolution was presented and adopted.

RESOLVED, that the AIEE recognizes the registration of engineers as a continuing practice and the Model Law for the registration of professional engineers and land surveyors, as adopted in 1943 and amended in 1945, as the widely accepted basis of its administration, and that the Institute endorses these procedures as well established.

In view of this more positive action and changed position of AIEE, it was recommended that a new standing committee be appointed replacing the present committee on registration of engineers and that it have a scope of responsibility covering matters related to registration, to be reported at a subsequent meeting. (This recommendation was adopted.) The drafting of scope was referred to the committee on planning and co-ordination.

Notification of AIEE endorsement has been sent to the ASCE sponsors of the Model Law and to the conference committee of the various societies.

The present Model Law is the result of compromise and is subject to revisions when needed and proposed by the conference committee for endorsement by constituent societies. In order for the new standing committee to be thoroughly representative of AIEE thought, it will be necessary for Sections to follow developments in their localities and inform the standing committee of local conditions and the considered reactions of their members, together with suggestions for desired alterations in Model Law.

General Committees

SECTIONS COMMITTEE

1. Section Programs. The Sections generally have been following a program of expanding their activities to meet the increased scope and growing demands of the electrical industry and to provide for the diversification of interest of the Section members. With the end of the war, it has been possible to give increased attention to student activities, social activities, more fellowship at meetings, inspection trips, and the broader subject of civic responsibilities of engineers. During the past year, Section officers have been generally more conscious of the importance of balanced Section operation, which provides activities to retain the older members as well as attract new members. In giving more time to creative work and the co-ordination of the activities of their Sections, many Chairmen have followed the suggestion of delegating to committees much of the operating work of running the Section. The increase in operating committees in the Section has resulted in more members working actively for the Section, which in turn has created additional interest.

2. Sections Committee Organization. Because of the volume of the Sections committee work, the committee again was organized at the beginning of the year into two groups. The planning group, consisting of six members, initiates and develops all plans of the committee. The promotional group consists of ten members located geographically on a District basis, making it possible to handle much of the promotional work individually with the Sections. Most of the material used by the promotional group is sent to each member, who in turn supplements it with his personal knowledge of local conditions, before contacting the Sections in his District. Close contact is maintained between the promotional group member and the vice-president of the District.

3. Conferences on Section Operation and Management Held in Connection With District Meetings. Due to the cancellation of the summer technical meeting in 1945, the usual delegates meetings were not held. A program for conferences on Section operation and management was developed by the Sections committee to be held at the individual District meetings early in the fall of that year. These meetings were presided over by the vice-president of each District. A detailed outline of the suggested conference was prepared by the Sections committee for the information and guidance of the vice-presidents. No conference was held in District 3—New York, and District 10—Canada. The Sections of the Canadian District divided their attendance between the meetings held in District 1 and District 9. These meetings were very successful as a substitute program for the regular delegates meetings and provided the Section officers with much information, enthusiasm, and inspiration for the conduct of the affairs of the Sections. The promotional group representatives of the Sections committee received special travel allowance to attend their respective meetings in each District.

These meetings were so well received by Section officers that the Section representatives recommended, at the Sections committee meeting in New York, January 22, 1946, that these District conferences on Section operation and management be continued as a supplement to the regular delegates meetings, which will be held at the summer convention.

4. Technical Groups. The development of technical groups is a very important part of the plan to retain the diversified interest of the older members as well as attract new members. The Sections committee sent a copy of the folder "Technical Groups" to each Section chairman at the beginning of the year and, through its promotional group, has been making individual contacts with those Sections where there is a possibility of the successful operation of these technical groups. The promotional group also has been supplying individual Sections with reports of examples of successful operation of these technical groups. The value of such groups operated within the Section is becoming more generally recognized throughout the country. There were 51 groups in active operation at the end of the 1944–45 operating year. Reports received from the Sections indicate 23 new technical groups have been formed to date this year. Many other groups are in process of being formed. The Sections have been asked to explore thoroughly their area to make certain that they have the entire field of electrical engineering covered by suitable technical groups.

5. Subsections. Subsection operation is a valuable means of accomplishing the important objective of the Institute, by providing additional meeting places at which papers on electrical engineering subjects may be presented and discussed. With all the territory in the continental United States allocated to the Sections, the next logical step forward in the development of Section activities was to form Subsections or additional centers of electrical engineering influence. Many opportunities exist for members in the remote areas of a Section territory to participate in Section activities through the development of Subsections in these area. A copy of the folder "Subsections" was sent to each Section chairman at the beginning of the year, and the promotional group of the Sections committee has encouraged the Sections to consider the opportunities which exist for the formation of additional Subsections. Examples of successful operation of Subsections were sent to the individual Sections by the promotional group. Subsection operation is becoming more popu-

lar each year as its advantages are more widely recognized. Ten additional Subsections have started operation during the year, and there are now 25 Subsections in active operation. Many additional locations for Subsections are being considered by the Sections.

6. Local Councils of Engineering and Technical Societies. Participation of AIEE Sections in the work of the local council in their community provides a means by which the Section members can engage in civic, legislative, and other similar broad activities of the engineering profession without the necessity of joining additional societies. Interest in these local councils during the past year has been very great throughout the country. There are now 43 councils in active operation, about half of which have been formed since 1940. Several additional councils are in process of being formed. In most cases not only the local AIEE Section has been very active in forming these councils, but also the members of the local AIEE Sections have been very active in the work of these councils. This activity has been encouraged during the past year by the Sections committee. On February 8, 1946, a letter was sent to all Section chairmen on the subject of these local councils. The promotional group has distributed to the Sections examples of the successful operation and organization of these local councils in various parts of the country. This Sections committee activity was designed to encourage AIEE Sections to become active in the formation of local councils in their areas where these councils do not exist and to encourage the Sections to become more active in local councils now in operation.

The Institute has representatives on a committee of the Engineers Joint Council for the organization of the engineering profession. This committee has approved for distribution to the local sections of the various societies, a report on the organization of local councils which closely parallels the information previously sent out by the Sections committee. The Sections of the co-operating societies have been requested to furnish certain information concerning local councils now in operation. This information is to be used by the committee to develop plans for regional and national organizations for the engineering profession.

7. Section Finance. In co-operation with the finance committee of the Institute, plans were formulated to provide for certain increases in appropriations to those Sections operating Subsections and technical groups. The plan for these additional appropriations was approved in principle by the executive committee of the Board of Directors and referred to the finance committee. The proposed increases will cover the cost of the expanded activities of the Sections, and it is hoped that final approval will be obtained to place them in effect for the 1946–47 operating year.

8. Student Activities. In co-operation with the committee on Student Branches, the Sections committee has developed a plan of co-operation between the AIEE Sections and the Student Branches. This plan was distributed simultaneously on April 1, 1946, to the officers of each Section and Branch, Student Branch counselors, vice-presidents and District secretaries. Under postwar conditions, the Student Branches are resuming normal activities. It is essential that the AIEE Student Branches develop, as early as possible, the interest of those students who select electrical engineering. The Sections can assist materially in this important activity. Such help from the Sections gains increased importance now because of the maturity of those returning to electrical engineering studies after service in the Armed Forces.

9. Educational Courses. In co-operation with the committee on education, the Sections committee released a letter to all Sections calling attention to the opportunities for additional Sections of the Institute to perform a worth-while service by offering educational courses to their members and others. The letter explains how these courses are conducted and lists several suggestions on possible courses which could be offered at the beginning of the 1946–47 operating year.

10. Changes in Section Territory. The following changes in Section territory were made during the year:

The Mexico Section was transferred from District 3 to District 7. This transfer was made with the approval of the vice-presidents of the two Districts concerned. The negotiations for the approval of the Mexico Section were handled by the Sections committee. This transfer places the Mexico Section in direct contact with the adjoining territory, which has resulted in increased interest of the Mexico Section in the affairs of the Institute.

The formation of the Illinois Valley Section was approved by the Board of Directors at its meeting on May 29, 1945. The territory of this Section comprises 22 counties in the State of Illinois, which were previously a part of the Urbana Section. This new Section was formed with the approval of the Urbana Section and the vice-president of District 5.

The formation of the Beaumont Section was approved by the Board of Directors on June 27. This Section comprises 13 counties in the State of Texas, which were formerly the territory of the Houston Section. This new Section was formed with the approval of the Houston Section and the vice-president of District 7.

11. Annual Report of Section Chairmen. An annual report of Section chairmen was prepared by the Sections committee and distributed to all Sections at the close of the 1943–44 operating year and the 1944–45 operating year. This report provides a simple analysis of major activities and the organization of all Sections and contains much information of value to new Section officers in laying out their Section program for the year. This report also is sent to all vice-presidents, District secretaries, and the chairmen of all national committees. Due to the wide acceptance of this report, it is planned to continue this feature at the close of the present operating year.

12. Section Operating Committees. On November 28, 1945, a letter was sent to all Sections suggesting the formation of additional Section operating committees in order to handle properly the increased activity within the Sections. The annual report of Section chairmen showed 348 committees reported for 1943–44, as compared with 410 committees reported for 1944–45. A list of suggested committees was given in this letter to the Sections. It was pointed out that spreading the work of the Section by the use of additional committees provides an opportunity for more members to participate actively in the work of the Section.

13. Section News Items for Electrical Engineering. A letter has been released to all Sections requesting news items for publication in *Electrical Engineering* and again requesting articles on subjects presented at Section meetings for possible publication in the general interest section of *Electrical Engineering*. This activity has the approval of the publication committee and was prepared with the co-operation of the editor of *Electrical Engineering*.

14. Co-operation With Other National Committees. In addition to close co-operation with the vice-presidents, certain features of the Sections committee program were co-ordinated with the Institute finance committee, membership committee, committee on Student Branches, and the committee on education.

Each of the Institute technical committees also was approached in an effort to obtain the co-operation of these committees in the development and operation of technical groups within the Sections. Several technical committees have participated actively in this program during the year, and it is believed that this work will serve as a pattern in the future for greater co-operation within the Institute.

15. Delegates Meetings at Summer Convention. The Sections committee has prepared a comprehensive program for the Institute officers, Section delegates, and members at the summer convention at Detroit. Three parallel conferences on Section operation and management will be conducted on June 24th, with the delegates divided into groups representing the larger, intermediate, and smaller Sections. The conference of officers, delegates, and members will be held on June 25th. On June 26th a conference on Section activities in connection with local councils of engineering and technical societies will be held, and on June 27th a conference on Section–Branch co-operation is scheduled as a joint activity of the Sections committee and the committee on Student Branches.

16. Committee Meetings. Due to the nature of the Sections committee work, the activities of the committee were carried on by means of correspondence. One meeting was held by the committee on January 22, 1946, in New York during the winter convention, with an attendance of 51. At this meeting the entire Sections

Table I. Section and Branch Statistics

	For Fiscal Year Ending April 30					
	1941	1942	1943	1944	1945	1946
Sections						
Number of Sections	72	72	73	73	73	75
Number of meetings held	703	647	598	738	884	1,210
Total attendance	92,554	78,254	66,111	83,120	96,346	113,531
Branches						
Number of Branches	123	124	125	125	125	125
Number of meetings held	1,163	946	942	755	547	716
Total attendance	52,285	37,785	38,227	24,768	17,132	22,844

committee program was reviewed, and plans for the remaining portion of the year were discussed. Minutes of this meeting were sent to all who attended and in addition were sent to all vice-presidents, District secretaries, and Section chairmen.

COMMITTEE ON STUDENT BRANCHES

The committee on student branches during the current year has exerted its efforts primarily toward the conversion of Student Branches from uncertain wartime operation to a stable, yet flexible, program of peacetime operation.

A major step has been taken in the reinauguration of District student conferences in connection with District meetings. Successful conferences in somewhat modified form have been held at the South West District meeting, San Antonio, April 16–18, and at the North Eastern District meeting, Buffalo, April 24–26. A more comprehensive conference has been planned and seems definitely destined for success at the Southern District meeting, Asheville, May 14–16.

For some time, a subcommittee on joint Student Branches, with J. F. Calvert as chairman, and comprising M. S. Coover, M. M. Cory, and J. E. Hobson, studied the possibilities of the operation of joint AIEE-IRE Student Branches, and at a meeting of the committee on Student Branches held in New York at the time of the winter convention, January 22, 1946, made the following recommendations, which were accepted by the committee on Student Branches and approved by the board of directors of the AIEE:

1. It is recommended that insofar as the establishment of joint AIEE-IRE Student Branches is concerned, that such branches not only should be permitted, but also should be encouraged, in accordance with the principles stated in the recommendations of the committee on planning and co-ordination. This should not be considered to oppose similar joint action with other technical societies.

2. It is recommended further that the board of directors of the AIEE be requested to take appropriate action in co-operation with the proper representatives of the IRE, and at the earliest opportunity, to arrange all details essential to the successful operation of these proposed joint Student Branches.

This means that Student members in either AIEE or IRE automatically share equal rights in joint Student Branches, in addition to the advantages offered by their particular society, and are eligible for admission to a regular membership grade in either participating society without entrance fee. It is hoped that such joint Student Branches eventually will include Student members of other societies of similar type and policy. The plan proposes, in general, an engineering council at the Student member and Student Branch level.

It is not intended that the identity of AIEE Student Branches be lost, for there will be many subjects and meetings of prime interest to AIEE Student members and of little or no interest to IRE members. Such meetings, as well as AIEE Student District conferences, and joint activities with AIEE Sections and Districts, will maintain the identity and independence of AIEE Student Branches, even while co-operating within their schools in joint Student Branches as recommended.

Arrangements also have been made to distribute in reprint form the excellent series of three articles on "The Unwritten Laws of Engineering" by W. J. King, formerly of the General Electric Company, and now with Battelle Institute.

After acceptance of these recommendations by the board of directors, this same subcommittee was requested to study and develop policies, programs, and practices, using Student Branches in the Chicago area as pilot projects, and to report their findings and recommendations to the committee on Student Branches at its annual meeting in connection with the summer convention in Detroit, June 24–28, 1946.

FINANCE COMMITTEE

Institute revenue has been sustained at a high level for the fiscal year as a consequence of growth in membership and a steady demand for Institute publications. Attention is directed to the detailed financial statements on pages 18, 19, and 20, and especially to Exhibit B in which report is made on cash receipts and disbursements, and the excess of income over expenditures is shown.

The budget presented to and approved by the board of directors provided for the effective continuance of all Institute activities and proper participation by the Institute in matters of common interest with other technical societies and associations. All expenditures have been in accordance with the intent of the budget items, some upward revisions of detailed figures having to be made to meet rising costs, especially in connection with items concerned with the publication of *Electrical Engineering*.

An amount of $1,762.38 was placed in the Member-for-Life fund, and the excess of income over expenditures has permitted the transfer of approximately $120,000 to the reserve capital fund. In addition, the Institute received last fall a bequest of $10,652 from the late W. S. Barstow without restrictions as to its use. This amount also was transferred to the reserve capital fund, and all such amounts invested in appropriate securities.

As of May 1, 1946, 1,800 members were on inactive status in accordance with the established policy to grant dues concessions on requests to those serving in the Armed Forces and merchant marine. The foregoing figure compares with 2,259 members in such status as of May 1, 1945.

A summary of the securities owned by the Institute as of April 30 is presented in Schedule 1. A substantial portion of the reserve capital fund is in United States Government bonds, and the market value of other securities will be noted to be favorable. The finance committee avails itself continuously of the advice of investment counsel in connection with the purchase and other negotiations concerned with securities, and all items in the present portfolio fund have been approved from the standpoints of appropriateness and diversification.

Institute expenditures are budgeted to come within anticipated income, and the present sound financial condition reflects the conservative policy that has been followed over the years. The steady growth of the reserve capital fund is indicative of the ability of the Institute to render the character of service to the membership that may be indicated to be desirable and gives assurance with regard to the availability of funds to continue at proper level essential activities at such times as income might be temporarily affected by unforeseeable influences or economic conditions.

TECHNICAL PROGRAM COMMITTEE

Reconversion Programs. With all Institute and District meetings, except the winter meeting, canceled in 1945 and with various strike situations in 1946 the arrangement of adequate technical programs during the reconversion period has been difficult. To substitute for the canceled 1945 meetings, spring, summer, and fall technical paper programs, with preprints of the papers available, were announced nationally and offered for discussion by mail. A comparison of the number of papers offered on the three programs by mail with the number of papers for the three corresponding meetings of the previous 12-month period is of interest. The results shown in Table II represent a 49.1 per cent decrease in the number of papers offered, notwithstanding the special efforts that were made to announce the substitute plans in advance and solicit papers to keep pace with the many developments. The comparison serves to illustrate the value of technical meetings as a stimulus for the production of technical papers on new developments to keep the membership informed of advances in the profession.

The 1946 winter convention was an outstanding success with a registered attendance of 2,624, which exceeded all previous records. Among the high lights of this convention was an address on the de-

velopment of atomic energy by Doctor J. R. Dunning at the general session, followed by an address in the evening on "Some Electrical Engineering and General Aspects of the Atomic Bomb Project" by Major General Leslie R. Groves, and a symposium on nuclear energy which brought together the views of well-known people in the fields of physics and research. The number of papers presented for the year and the number recommended for the *Transactions* are shown in Table III.

Analysis of Subject Matter. The papers for the year have been analyzed on a percentage basis and classified into six broad fields of electrical engineering. In Table IV, the classification is compared with an occupational analysis of the membership made in 1940. When it is considered that those engaged in electrical manufacturing and educational work have considerable interest in all of these fields, the comparison indicates a reasonably close correlation between the percentage of papers presented in the first three fields and the percentage of the membership occupied in those fields. With the abandonment of wartime restrictions, it is apparent that material in the industrial and communication fields has come to the fore. The 20.3 per cent papers in the industrial and railroad fields represents a fairly uniform distribution of subject matter into subjects such as electric welding, industrial distribution, quality control and statistical methods, induction and dielectric heating, industrial control, and railways. In the field of communication, seven of the papers were on the subject of radar. As might be expected with the end of the war, the number of air transportation papers has decreased from a high of 37.5 per cent for the previous year to 13.1 per cent for the past year. The program for the forthcoming summer convention will bring forth additional papers in the fields of communication, industrial control, and servomechanisms, which heretofore have been highly restricted.

Exploratory Work. The committee has worked in close co-operation with the committee on planning and co-ordination in connection with the study of the organization of the engineering profession and the technical activities of the Institute. The technical committee chairmen have analyzed the methods of operation of some 44 other engineering societies, as a background for further consideration in organizing the technical activities. With a membership of 24,526 on January 1, 1946, and an increase of 1.33 per cent since January 1, it is not unreasonable to expect an average membership for the next five years of 28,000 members and an average number of papers per year of approximately 270. The increase in membership and the average number of papers during two 5-year periods is shown in Table V. Steps already have been taken to provide for this expansion and to keep the membership fully informed of new developments in the field of electrical engineering.

The committee has recommended that the chairmen of technical committees review all contacts with similar committees of other organizations and explore the possibilities of establishing new contacts in accordance with Section 86 of the bylaws. Closer ties with the District meeting committees and Sections have been suggested, with the recommendation that technical committees give consideration to planning important sessions on specific subjects appropriate for the localities of District meetings. It was further recommended that the Institute should adopt the policy of supplementing the three national conventions with another national convention to be held annually in the Midwest in October.

Table II. Comparison of Programs by Mail, When Meetings Were Restricted, With the Programs for the Three Previous Corresponding Meetings in 1944

	Transactions Papers		Transactions Papers
Spring technical paper program	19	Boston	12
Summer technical paper program	31	St. Louis	85
Fall technical paper program	30	Los Angeles	60
Total	80	Total	157

Per cent decrease $\frac{157-80}{157} = 49.1$ per cent

Table III. Number of Papers Presented During the Year Ending April 30, 1946

	Number of Papers	Number of Transactions Papers
Spring technical paper program	19	19
Summer technical paper program	31	31
Fall technical paper program	30	30
Winter convention	78*	68
San Antonio meeting	21	3
Buffalo meeting	33	2
	212	153

* Includes 3 representations from summer and fall technical paper programs.

Discussions are being carried on with the publication committee to permit publication of papers arising from joint meetings with other societies. The technical program committee and the publication committee are working jointly on an analysis of suggestions received through the study of the Institute's technical activities which pertain to publication policies.

To provide greater interest for younger members, the committee has recommended that a study be made with a view toward holding commercial exhibits at conventions rather than excluding them. The committee also recommended to the winter convention committee that the next winter convention be held in a hotel rather than in the Engineering Societies Building.

PUBLICATION COMMITTEE

The publication activities during the year have been influenced strongly by the termination of hostilities in World War II, which lifted many wartime controls, and by the cancellation of AIEE national and District meetings after February 1, 1945, which greatly reduced the material available for publication. Publication policies and procedures remained unchanged as papers and discussions resulting from the technical paper programs, which replaced the usual meetings, were treated in the normal manner.

In accordance with current publication policies, the 1945 *Transactions* volume contains all approved 1945 technical papers

Table V. Growth in Membership and Expected Average Number of Papers in the Next Five Years

	Approximate Average Membership	Average Number of Papers Per Year
5-year period following 1925	18,000	160
5-year period following 1940	20,000	200
5-year period following 1945	28,000*	270*

* Forecast

Table IV. Comparison of Classification of Papers in Six Broad Fields With an Occupational Analysis of Membership as of 1940

	Per Cent of Papers	Occupational Analysis of Membership (1940 Survey)	
Central stations	27.4	Light and power	25.5
Communication	13.7	Communication	9.7
Industrial and railroad	20.3	Industrial and railroad	11.4
Air transportation	13.1	Government	5.9
Electric machinery	14.4	Electrical manufacturing	25.8
Basic sciences and measurements	11.1	Educational	5.4
		Consultants and large contractors	4.4
		Miscellaneous	11.9
	100 per cent		100 per cent

and related discussions. Two semiannual "Supplements to Electrical Engineering—Transactions Section" were produced, on the usual limited-edition advance-order basis, containing (1) technical papers that could not be accommodated in the monthly *Transactions* sections of *Electrical Engineering*, and (2) all approved discussions.

Relaxation of strict censorship controls was reflected in the increased content devoted to wartime developments.

The easing of restrictions on paper supply permitted a return in January 1946 to the larger trim size and to the format that had been used in *Electrical Engineering* in 1943. A paper somewhat heavier than that used in 1945, but still not so heavy as the prewar paper, also was obtained.

The reduction in material for publication caused primarily by the cancellation of meetings, but possibly influenced also by the letdown following the end of fighting, is shown by a comparison of the numbers of pages of various classes of material published in the calendar years 1944 and 1945, as compared with 1941 as the last prewar year:

Numbers of Pages of Published Material

	Electrical Engineering			Transactions Only		
Year	General Interest Articles	News	Transactions Section	Technical Papers	Discussion	Total
1941	337	281	600	542	268	2,028
1944	246	214	738	493	231	1,922
1945	255	225	736	121	143	1,486

It may be noted that the number of pages in the "Transactions" section of *Electrical Engineering* in 1945 was maintained by publishing therein a greater proportion of the year's total of technical papers than was done in 1944. The use of a paper of lighter weight and the easing of paper restrictions in the latter part of 1945 permitted the number of pages in *Electrical Engineering* to be held at a fair level in spite of an increase in the number of copies printed, from 26,250 in December 1944 to 28,750 in December 1945. It was possible also to restore the 1945 annual report of the AIEE board of directors and the annual reference index to complete circulation. Only a limited distribution had been made in 1944 in order to conserve paper for text pages.

Advance pamphlets of approved technical papers were produced as required by the technical program committee for discussion by mail on summer and fall programs in 1945, and for regularly scheduled meetings beginning with the winter convention in January 1946.

The quarterly AIEE "Bulletin" for Institute members in the armed services was continued through the issue of February 1946. The number of members receiving the "Bulletin" decreased rapidly with the demobilization of the Armed Forces.

Revision of the booklet, "Information for Authors," to which reference was made in last year's report of this committee was deferred.

MEMBERSHIP COMMITTEE

It is quite interesting to note at this time that the growth in membership for the year 1945–46 has exceeded by a considerable margin the gain of any previous year in the history of the Institute. The net gain is 2,018 which brings the total membership to 25,090. The rate of gain in 1945–46 was 8.7 per cent, and the rate of gain for the 1944–45 period was 7.8 per cent. In the past two years, the numerical net gain has been 3,683. Judging from the rate at which new applications and applications from former members for reinstatement or re-election are being received, it would appear that the membership for the coming year is destined to continue to increase at a high rate.

The number of persons who were classified as having an "inactive status" because of military service or for other causes resulting from World War II was 2,259 at the end of the fiscal year 1944–45. This number increased to approximately 2,500. However, on April 30, 1946, the total had dropped to 1,809. This is a favorable trend and demonstrates the desire of the persons in this classification to return on their own motion to active membership status as promptly as possible. The policy of the Institute in this connection seems to have proved to be quite beneficial.

Starting in the year 1942, a renewed interest in the Institute was manifested by persons who had been members formerly. During that year, 237 were either reinstated or re-elected to membership. In 1943–44 the number in this group was 301. The corresponding numbers for the years 1944–45 and 1945–46 are 366 and 401, respectively. This trend is significant, as is the fact that the number in arrears for the fiscal year April 30, 1946, is only 954 or 3.8 per cent of the total membership. It will be recalled the corresponding number for those in arrears for 1944–45 was 902.

The number of transfers from the Associate and Member grades to higher grades of membership was 559. This number corresponds with totals of 464 and 420, respectively, for the years 1944–45 and 1943–44.

The total losses in membership for the year (Deductions, Table VI) was 600, or 102 lower than in 1944–45. From the same table, it will be seen that the total new members qualified was 2,217, an increase of 216 over the corresponding period in the previous year. The membership, not including Student members, is divided as follows:

Membership Grade	Per Cent
Honorary	0.04
Fellows	3.93
Members	27.47
Six-Year Associates	29.29
Associates	39.27
	100.00

The Member and Associate Grades have increased 0.44 per cent and 0.48 per cent, respectively, while the six-year Associate grade has decreased 0.90 per cent.

From Table VII, it will be noted that the number of applications from the Student members is once more ascending and that the applications from all other sources increased by 274 or 12.7 per cent. The total increase in applications was 333 or 13.7 per cent. No direct comparison between this Table and Table VIII can be made, since all applications received during the

Table VI. Membership Statistics for Fiscal Year Ending April 30, 1946

	Honorary Members	Fellows	Members	6-Year Associates	Associates	Subtotals	Totals
Membership April 30, 1945	6	914	6,238	6,963	8,951		23,072
Additions							
New members qualified		2	262		1,953	2,217	
Former members reinstated or re-elected		1	134	80	186	401	
Subtotals		3	396	80	2,139	2,618	
Transfers	3	90	466	925		1,484	
Totals	3	93	862	1,005	2,139	4,102	
Deductions							
Died		16	51	45	15	127	
Resigned			30	90	36	156	
Dropped			38	107	172	317	
Subtotals		16	119	242	223	600	
Transfers		3	89	378	1,014	1,484	
Totals		19	208	620	1,237	2,084	
Net changes	3	74	654	385	902	2,018	
Membership April 30, 1946	9	988	6,892	7,348	9,853		25,090

Table VII. Number of Applications Received From Student Members and From All Others

Year Ending April 30	Students	All Others	Total
1946	308	2,453	2,761
1945	249	2,179	2,428
1944	466	1,908	2,374
1943	783	1,431	2,214
1942	971	1,031	2,002

Table VIII. Number of Student Members as of April 30

Year	New Applications	Renewals	Total
1946	2,574	2,513	5,087
1945	2,326	2,287	4,613
1944	2,242	2,656	4,898
1943	2,512	3,200	5,712
1942	2,585	3,377	5,962

fiscal year are not acted upon before the close of that year.

Table VIII shows a marked renewed activity in Student membership. The increase in new applications is 248 while the increase in renewals is 226, bringing the total increase to 474. The Student membership now stands at 5,087.

Table IX is a record of the total membership of the Institute by years since 1884 and is given for information purposes.

Table X is the usual listing of the names of AIEE members reported in *Electrical Engineering* as having died during the fiscal year 1945–46. By this method a ready reference is provided.

The new booklet which was reported last year as being under preparation by the membership committee for use particularly when contacting prospects for membership in the Institute has been completed. It is an attractive, brief, concise publication of handy pocket size which already has been enthusiastically received.

There is much in the data relative to membership activity which should be of considerable interest to every person in the Institute. The growth has exceeded all expectations. It seems to be due to a strong interest on the part of the members generally, the enthusiastic co-operation of the entire membership committee personnel and the ever ready progressive co-operation of the members of the staff at the Institute headquarters. Undoubtedly, also the present economic situation and probable future trends in the scientific and industrial world are factors which have contributed to this rather unusual growth.

Table IX. Record of AIEE Membership

Year	Total May 1	Year	Total May 1	Year	Total May 1
1884	71	1905	3,460	1926	18,158
1885	209	1906	3,870	1927	18,344
1886	250	1907	4,521	1928	18,265
1887	314	1908	5,674	1929	18,133
1889	333	1909	6,400	1930	18,003
1890	427	1910	6,681	1931	18,334
1891	541	1911	7,117	1932	17,550
1892	615	1912	7,459	1933	17,019
1893	673	1913	7,654	1934	15,230
1894	800	1914	7,876	1935	14,269
1895	944	1915	8,034	1936	14,600
1896	1,035	1916	8,202	1937	15,308
1897	1,073	1917	8,710	1938	16,078
1898	1,098	1918	9,282	1939	16,605
1899	1,133	1919	10,352	1940	17,213
1900	1,183	1920	11,345	1941	17,886
1901	1,260	1921	13,215	1942	18,944
1902	1,549	1922	14,263	1943	20,161
1903	2,229	1923	15,298	1944	21,407
1904	3,027	1924	16,455	1945	23,072
		1925	17,319	1946	25,090

Table X. Deaths of AIEE Members Reported in "Electrical Engineering"

Name	Date of Election	Date of Death	Grade at Death	Obituary Notice in "Electrical Engineering"
Acres, H. G.	A '08	Sept. 4, '45	M	Oct. '45, p. 373
Adams, H. H.	A '06	Jan. 31, '45	M	May '45, p. 197
Allason, A. R.	A '32	June 5, '45	M	Sept. '45, p. 337
Angle, F. C.	A '38	Oct. 25, '45	A	Jan. '46, p. 41
Barger, C. A.	A '44	Apr. 2, '45	A	July '45, p. 274
Barney, G. C.	M '37	May 11, '45	M	July '45, p. 274
Battit, B. E.	A '35	Oct. 11, '44	A	Nov. '45, p. 415
Beall, C. R.	A '18	Feb. 24, '45	A	June '45, p. 232
Bell, A. C.	A '01		A	June '45, p. 232
Bingham, A. R.	A '07	Jan. 4, '46	M	Mar. '46, p. 136
Blickley, C. F.	M '44	Nov. 11, '45	M	Jan. '46, p. 40
Blumberg, Ralph Dietz	M '44	Oct. 30, '45	M	Jan. '46, p. 40
Bolsterli, A. A.	A '23	Sept. 25, '45	M	Dec. '45, p. 459
Bonine, J. H.	A '17	May 12, '45	A	Aug. '45, p. 306
Booth, Wm. S.	A '44	May 3, '45	A	July '45, p. 275
Brewster, Truman P.	M '44	Jan. 7, '45	M	July '45, p. 275
Brown, Harry C.	A '20	Feb. 21, '45	A	July '45, p. 274
Brubaker, Leonard H.	A '42	Sept. 30, '45	A	Jan. '46, p. 40
Buchner, Robert O.	M '36	July 23, '45	F	Nov. '45, p. 415
Caldwell, C. W.	A '32	June 5, '45	A	Aug. '45, p. 306
Chatham, Clyde L.	A '25	June 7, '45	M	Sept. '45, p. 338
Clarkson, A. J.	M '26	June 4, '45	F	Aug. '45, p. 306
Conwell, R. N.	A '15	Apr. 14, '45	F	May '45, p. 197
Corson, Wm. R. C.	A '93	Oct. 2, '45	A	Dec. '45, p. 459
Creese, M.	A '07	Oct. 16, '45	M	Nov. '45, p. 415
Cushing, H. M.	A '06	Jan. 31, '45	F	May '45, p. 197
Davis, John M.	A '34	Aug. 13, '45	A	Oct. '45, p. 373
Donovan, J. D.	A '39	Dec. 20, '44	A	June '45, p. 232
Dudley, A. M.	A '08	Aug. 16, '45	F	Oct. '45, p. 373
Dyer, Leslie L.	A '10	Aug. 24, '45	M	Dec. '45, p. 458
Enfield, W. L.	A '10	Mar. 21, '45	F	May '45, p. 198
Faucett, Irving T.	A '11	Jan. 16, '46	F	Apr. '46, p. 179
Flowers, Alan Eatis	M '04	Dec. '45	M	Jan. '46, p. 40
Fowle, F. F.	A '02	Jan. 21, '46	M	Mar. '46, p. 135
Frank, Harry C.	M '41	June 9, '45	M	Sept. '45, p. 338
Gabay, Henry R.	A '07	Jan. 12, '46	M	Feb. '46, p. 90
Gaster, P. G.	A '04	May 18, '45	F	July '45, p. 273
Haddow, A. B.	M '35		M	June '45, p. 232
Hanson, C. F.	A '18	Apr. 27, '45	M	Aug. '45, p. 306
Harvey, R. B.	A '95	Feb. 20, '45	A	July '45, p. 275
Hedges, Leo B.	A '28	Nov. 30, '45	M	Feb. '46, p. 90
Herman, J. W.	A '07	Mar. 30, '45	A	May '45, p. 197
Hertz, Adolph	A '18	May 31, '45	A	Aug. '45, p. 306
Highfield, John S.	F '42	Aug. 15, '45	F	Oct. '45, p. 373
Hill, Warren Rhodes	A '24	[illegible] 7, '45	A	July '45, p. 274
Hoeckstetter, Lionel	A '35	May 8, '45	A	July '45, p. 274
Holder, Edward	A '13	Dec. 20, '45	M	Mar. '45, p. 136
Holslag, C. J.	M '19	June 11, '45	F	July '45, p. 273
Horrell, C. R.	A '16	July 5, '45	M	Aug. '45, p. 306
Horton, Bryson D.	A '14	Dec. 14, '45	A	Feb. '46, p. 90
Hutchinson, George E.	A '11	Oct. 20, '45	M	Dec. '45, p. 459
Ilsley, Lee Clyde	A '14	Nov. 23, '45	A	Jan. '46, p. 40
Jackson, Frederick D.	M '42	Dec. 19, '45	M	Feb. '46, p. 90
Kahler, Chas. Porterfield	A '10	Feb. 25, '46	M	Apr. '46, p. 180
Kahn, M. L.	A '20	July 25, '45	A	Oct. '45, p. 373
Karr, E. P.	A '40	Jan. 6, '45	A	Aug. '45, p. 306
Kelly, Walter Stuart	M '04	July 4, 45	A	Jan. '46, p. 40
Laidlaw, H. A.	A '09	Dec. 15, 45	M	Mar. '46, p. 135
Lindquist, D. L.	A '04	Nov. 11, '45	A	May '45, p. 198
Lovejoy, Jesse R.	A '91	Oct. 31, '45	F	Dec. '45, p. 459
Lowther, C. M.	A '00	Apr. 12, '45	A	July '45, p. 274
MacDonald, W. P.	M '43	Nov. 30, '45	A	Feb. '46, p. 90
MacLaren, Malcolm	A '05	Sept. 25, '45	M	Nov. '45, p. 415
Mason, E. J. K.	A '07	Feb. 23, '45	A	May '45, p. 198
McCormick, B. T.	A '04	Apr. 20, '45	F	July '45, p. 273
McElroy, D. W.	A '19	Dec. 13, '45	A	Jan. '46, p. 41
Moore, Leonard J.	A '15	June 4, '45	F	Sept. '45, p. 337
Myler, F. J.	A '07	Apr. 20, '45	A	June '45, p. 232
Neller, S. G.	A '94	Feb. 28, '45	F	May '45, p. 198
Palmer, H. R.	A '08	June 16, '45	M	Aug. '45, p. 306
Patton, G. J. K.	A '39	Aug. 17, '45	A	Jan. '46, p. 41
Pease, H. C.	A '03	May 5, '45	A	July '45, p. 274
Pedersen, P. R.	A '23	Apr. 4, '45	A	Nov. '45, p. 415
Perkins, Chas. A.	A '05	Nov. 26, '45	F	Jan. '46, p. 40
Perry, Chas. L.	A '03	Nov. 20, '45	A	Feb. '46, p. 91
Petrasek, Wm. August	A '36	Jan. 31, '46	A	Mar. '46, p. 136
Poole, W. C.	M '39	Oct. 16, '45	M	Sept. '45, p. 337
Potts, L. M.	A '02	Oct. 23, '45	M	Jan. '46, p. 39
Price, C. A.	A '19	Dec. 29, '45	M	Mar. '46, p. 136
Pullen, M. W.	A '07	Jan. 10, '46	M	Mar. '46, p. 136
Putman, H. V.	A '23	Jan. 16, '46	M	Mar. '46, p. 136
Reinicker, N. G.	M '18	Jan. 13, '46	M	Feb '46, p. 90
Rhodes, W. K.	A '09	Dec. 12, '45	M	Jan. '46, p. 41
Richards, A. F. W.	A '17	Jan. 25, '46	M	Mar. '46, p. 136
Ross, L. E.	A '29	Dec. 22, '45	A	Apr. '46, p. 180
Rowe, B. F.	A '05	Sept. 21, '45	F	Dec. '45, p. 459
Spaulding, S. A.	A '05	May 25, '45	F	July '45, p. 274
Symbolic, A. J.	A '42	Apr.	'45 A	July '45, p. 275
Thomas, Wilbur Cover	A '24	Feb. 27, '46	M	Apr. '46, p. 180
Van Slyck, C. H.	A '03	Dec. 31, '45	A	Feb. '46, p. 90
Vincent, Wm. G.	A '05	Jan. 29, '46	A	Mar. '46, p. 135
Voorhees, W. N.	A '10	Jan. 18, '46	A	Mar. '46, p. 136
Waddell, C. R.	A '02	Apr. 20, '45	F	June '45, p. 232
Wallace, John Napier	M '14	Nov. 4, '45	F	Apr. '46, p. 179
Ward, B. D.	A '45	Jan. 18, '46	A	Mar. '46, p. 135
Westman, A. A. J.	A '07	June 22, '45	M	Sept. '45, p. 338

BOARD OF EXAMINERS

Statistics relating to the number of cases handled are given in Table XI. Members of the board have attended the scheduled monthly meetings very regularly, and the volume of work has justified fully the increased number of members which was arranged early in the season 1945–46.

The board wishes to reiterate its recommendation that local Section membership and transfer committees shall exercise more care in submitting applications, to insure that they are in line with constitutional requirements and particularly that they shall contain extensive and detailed experience records of the candidates which will reveal the degree of responsibility these candidates have had in connection with their various assignments.

It has been noted that an excessive amount of time has been consumed by the members of the board of examiners in interpreting the records of the candidates, and in too many cases applications have had to be returned for additional information, which in its opinion places an undue burden on the headquarters office.

Table XI. Applications for Admission and Transfer*

Applications for Admission		
Recommended for grade of Associate	1,464	
Re-elected to the grade of Associate	129	
Not recommended	8	
		1,601
Recommended for grade of Member	334	
Re-elected to grade of Member	23	
Not recommended	65	
		422
Recommended for grade of Fellow	2	
Re-elected to the grade of Fellow	0	
Not recommended	0	
		2
Applications for Transfer		
Recommended for grade of Member	450	
Not recommended for grade of Member	28	
		478
Recommended for grade of Fellow	90	
Not recommended for grade of Fellow	4	
		94
Students		
Recommended for enrollment as Students		1,568
Total		4,165

* This tabulation does not include April 1946 meeting figures.

COMMITTEE ON TRANSFERS

The members of the committee on transfers have co-operated actively during the year with the many Section officers and transfer committees of the Institute, explaining the requirements of the several grades of membership, and the required qualifications for transfer from Associate to Member and from Member to Fellow.

During the present year there have been a large number of transfers from the grade of Associate to Member and from Member to Fellow throughout all parts of the United States and Canada served by the AIEE.

COMMITTEE ON MEMBERS-FOR-LIFE FUND

Members-for-life awards, namely, expenses of District Branch paper prize winners to the summer convention of the Institute, will be made this year for the first time in connection with the Detroit meeting.

Last November, Secretary Henline invited the attention of the vice-presidents of the even-numbered Districts to the availability of these awards as described in *Electrical Engineering* for January 1945, page 31.

It will be recalled that this form of award financed by the income from the members-for-life fund, is on trial for two years—for even-numbered Districts this year and for odd-numbered Districts next year. The interest shown in this form of award this year and next year will determine whether or not it will be continued.

COMMITTEE ON CODE OF PRINCIPLES OF PROFESSIONAL CONDUCT

This committee held no formal meetings during the year but carried on its activities by correspondence. Various members of the committee have been active in their geographical areas and local engineering societies in bringing to the attention of engineers and others the Institute's code of principles of professional conduct and in advancing the Engineers Council for Professional Development canons of ethics for engineers.

One case of alleged violation of professional ethics by an Associate of the Institute has been brought to the attention of the committee and is still under consideration.

COMMITTEE ON CONSTITUTION AND BYLAWS

On January 4, 1946, the committee on constitution and bylaws made the following recommendations to the board of directors:

1. An amendment to Section 48 of the bylaws changing the basis of allotting funds to the Sections in order to conform with the action of the board on November 2, 1944.

2. An amendment to Section 65 of the bylaws, adding the name of a new committee on industrial control devices to the list of technical committees.

3. Changes in the bylaws transferring the Mexico Section from District 3 to District 7.

4. The word "national" to be deleted from the bylaws whenever it occurs in connection with the titles of officers, committees, and meetings. This was in line with similar action taken last year in eliminating the word "national" from the titles of officers, committees, and meetings wherever it occurred in the constitution.

On March 13, the committee recommended an amendment to Section 51 of the bylaws to make the definition of a "university or technical school of recognized standing" consistent with our present-day practice of accrediting engineering schools by the ECPD.

Recent action by the board of directors brings two more amendments to the committee for consideration. It is hoped that these can be presented to the board and action taken before the close of this administrative year. They are:

1. To amend the list of standing committees to include a committee on registration of engineers to succeed the present special committee of that name.

2. To amend the bylaws to provide for holding four conventions each year instead of the present practice of three per year, the new meeting to be known as the "mid-west convention."

COMMITTEE ON PLANNING AND CO-ORDINATION

The project of reviewing the technical activities of the Institute and the Institute's relations with other organizations, which was assigned to the committee, is being carried out by the technical activities subcommittee and the professional activities subcommittee. These subcommittees are studying the problems to recommend any changes in organization or methods that may seem desirable to render the structure and the procedures of the Institute sufficiently flexible and adaptable to take account of progress in the art and the development of new fields of interest, and to respond promptly to changing social, political, economic, and other conditions affecting the welfare of society and of engineers.

A conference on Institute activities was conducted by the subcommittees on Wednesday, January 23, at the winter convention, as a first step toward finding out what the members believe the Institute should be doing or should do in a different way. The technical part of the discussion included suggestions for regional meetings on specific subjects and reorganizing the technical committee structure to form semiautonomous technical divisions to foster and correlate technical activities in related subject fields. During the professional activities part of the conference, four proposed plans for organizing the engineering profession were presented and discussed. Opinions were expressed on many phases of the organization problem including collective bargaining and unionization of engineers.

The technical activities subcommittee is also a working group of the technical program committee and thus accomplishes many of its projects through this committee. This close interrelation results in co-ordinated consideration of technical activity and organization matters.

The executive committee approved and referred to the committee on constitution and bylaws the recommendation of the subcommittee and the technical program committee that an annual Midwest Convention be held. Other joint projects are described in the technical program committee's report.

The professional activities subcommittee has arranged for representatives to participate in discussions of Institute activities at Section meetings in Boston, Lynn, Pittsfield, and New York; and at District meetings as follows: the North Eastern in Buffalo, N. Y., the Southern in Asheville, N. C., and the South West in San Antonio, Tex.

The problem of organizing the engineering profession is one of the main interests of the subcommittee. A questionnaire has been prepared to obtain the opinions of members who attend the meetings where the matter is discussed. The four proposed plans for organization of the engineering profession originally presented at the winter convention have been revised and

published in *Electrical Engineering* and are now available as a reprint.

The executive committee approved a recommendation originated by the subcommittee to replace the special committee on registration of engineers by a standing committee. A draft of the scope and duties for this committee was submitted as requested by the board of directors. A recommendation for forming joint Student Branches also was approved by the board of directors and referred to the committee on Student Branches with the suggestion that the latter work with representatives of other societies in developing a specific plan of co-operation.

A study is under way as to how to relieve the president of some of the burden of his office.

The subcommittee is endeavoring to find out what the problems and needs of the younger engineer-employees are, and what the Institute can do to get and keep their interest.

COMMITTEE ON SAFETY

The committee held one meeting during the past year, at the winter convention.

Through arrangements with the American Medical Association the paper by Doctor C. K. Drinker on "Use of Drugs in Resuscitation from Electric Shock" was published in the *Journal* of the American Medical Association, June 30, 1945. This paper which had been presented at the committee's meeting in January 1945, also appeared in *Electrical Engineering*, August 1945.

Under the heading "Safety Topics" in the January 1946 issue of *Electrical Engineering*, the committee directed attention of Institute members to the importance of safety engineering work in the postwar period as set forth in the National Safety Council publication, "Industrial Safety Tomorrow."

At the January 1946 meeting, the committee again emphasized the importance of promoting safety engineering work in the Student Branches and Sections, and formulated plans for appropriate communications to the Student Branch counselors and Section officers.

Report was received from the Institute's representatives on the electrical committee of the National Fire Protection Association concerning the adoption in Chicago during October 1945 of revisions of the National Electrical Code, of which the 1946 edition is expected to be issued before the end of this year.

The committee contemplates resumption of its work with the AIEE committee on domestic and commercial applications on the study of electrical hazards to farm animals, which had been started and had to be deferred because of war conditions.

The attention of the committee was directed to the report on fatalities in the electric light and power industry during the year 1944 as prepared by the Edison Electric Institute accident prevention committee. Over the past four years, an average of 81 per cent of the fatalities in that industry have been shown to be due to electric shock and burn, and the committee recognizes the importance of steps being taken to stress the fundamentals of this matter in appropriate ways for the benefit of Institute members concerned.

Plans were completed for a session under the auspices of the committee during the 1946 summer convention, and there was discussion of important subjects in the field of electrical safety, on which it is planned to have papers prepared or other appropriate presentations made for discussion at the forthcoming national meetings.

W. T. Rogers was appointed to serve as liaison representative of the committee with the American Society of Safety Engineers, and W. R. Smith will continue to serve in such capacity with the accident prevention committee of the Edison Electric Institute.

UNITED STATES NATIONAL COMMITTEE OF THE INTERNATIONAL ELECTROTECHNICAL COMMISSION

During the past year, as in the preceding war years, the work of the International Electrotechnical Commission and the United States National Committee has remained virtually in a state of suspension.

At its annual meeting on November 9, 1945, the United States National Committee re-elected E. C. Crittenden, president; L. F. Adams, vice-president; and H. S. Osborne, vice-president and treasurer.

Looking toward the reactivation of IEC work, appointments of several new technical advisers were made. Considerable interest has been expressed in the international work on letter symbols, USNC 25, and, upon recommendation of the three new technical advisers for USNC 25, the United States National Committee took action at its meeting to authorize the circulation for comment in this country and to other national committees of a draft of the IEC symbols which had been adopted in 1938, together with additions prepared by a subcommittee authorized in 1938. The JSNC has acted as secretariat for this work.

During the year, the French committee requested comments on their proposals for standardization of very high voltages. The matter was referred to the technical adviser for the USNC (USNC 8) on the subject, and while no report was available, it was hoped that an answer to the French proposals could be made soon. The United Nations Standards Co-ordinating Committee was very hopeful that action could be taken on this matter, since a number of the European countries, particularly France, which were faced with rebuilding their power systems, were anxious to rebuild the systems using standard voltages.

At the USNC annual meeting, there was a discussion of reorganization of international standardization work. The United Nations Standards Co-ordinating Committee had just concluded meetings in New York and had drafted a proposed constitution for an international organization. A proposal has been made that the IEC become affiliated with the new organization and operate officially in the future as the electrical division of the new organization, retaining, however, all its functions and procedures. A subcommittee of the executive council of the UNSC was appointed to study from the point of view of the USNC the proposals for the method of affiliation of the IEC with the new organization.

It is now expected that a meeting of the council of the IEC will be held during 1946 and that the technical work of the commission will be resumed shortly thereafter. Many countries, particularly those in Europe, are anxious that IEC work be resumed, in order that some of the problems arising from reconstruction work may be solved by the IEC.

Standards

STANDARDS COMMITTEE

During the past year, the work of the Standards committee continued to be hampered by the restrictions which still existed with regard to traveling and to hotel accommodations. The curtailment, however, has been confined largely to a limitation of the number of meetings held, of which there were three. The various committees carrying on standardization activities have continued to make satisfactory progress by correspondence, although that procedure also has suffered recently through the strikes in progress in the larger industrial groups.

The various technical committees which now carry on much of the preliminary work in the development of new standards projects, as well as any required revisions of existing standards, have reported a large number of new projects in preparation, many almost ready for action. Among these may be listed the following: test code for resistance measurement; test code for temperature measurement; standard method of calculating the short-circuit currents in low-voltage circuits; standards for roof, floor, and wall bushings and for potheads; and standards for mercury-arc rectifiers. Under the auspices of the standards co-ordinating committees, the following projects also have been reported as well under way: standard barometric pressure and air density versus altitude; guiding principles for dielectric tests; letter symbols for electrical quantities; temperature rises for silicone insulation; and standard voltages from 100 to 15 kv.

In the field of electric aeronautical equipment, the standardization carried on by the Institute and other interested organizations is going forward, although curtailed in some of its phases by the changeover from wartime activities.

The following projects were approved and published during the year: AIEE Standard 45 "Recommended Practice for Electric Installations on Shipboard"; Numbers 601 and 602, "Preferred Standards and Standards Specification Data for Large 3,600-Rpm 3-Phase 60-Cycle Condensing Steam Turbine Generators"; Number 503 "Test Code for Synchronous Machines"; ASA Standard C37.4 to C37.9, "A-C Power Circuit Breakers."

As a result of the many reorganizations brought about by the end of the war, it has been necessary to make a large number of new appointments of AIEE representatives serving on various sectional committees of ASA.

The electrical definitions project, under the auspices of sectional committee C42 and the sponsorship of the Institute, inactive since publication of the first edition of the American Standard in 1942, now is being reorganized. While the addition of a large number of new definitions has been suggested, the criticisms of existing definitions have been few. On completion of the main committee personnel, the reorganization of the 18 or more subcommittees will be undertaken and all suggestions referred to them for inclusion in a new edition.

The subcommittee on applications of statistical methods has pursued an active program during the year. The educational articles which appear in *Electrical Engineering* will conclude with XII. The subcommittee then proposed to prepare and publish at least six more articles of a more advanced character.

A very successful conference was held during the winter convention in New York, and similar conferences have been arranged for the Buffalo and Detroit meetings. At the latter meeting the theme will be the management and organizational aspects of quality control. It is hoped that a conference also can be arranged at all of the remaining district meetings during 1946.

Technical Committees

COMMITTEE ON AIR TRANSPORTATION

The proceedings of the committee on air transportation during the past year were greatly handicapped by extensive reconversion of industry, shifting of personnel, and the ban on meetings and traveling. In spite of these obstacles, good progress was made in the standardization activities assigned to the committee.

These activities were carried on by several subcommittees, four of which were formed during the previous year, with assignments as outlined in the report for last year.

Aircraft Electric Systems. This subcommittee has accumulated approximately one half of the material required to complete the proposed guide report on aircraft electric systems in accordance with the outline completed last year. Cooperation of interested aeronautical groups, including Aeronautical Radio, Inc., has been very good, after some initial misunderstandings were cleared up.

Aircraft Electric Rotating Machinery. This subcommittee met several times during the year, and at a meeting held January 22 completed the proposed test code for d-c aircraft motors, except for final editorial revision. Editorial revision has been assigned to a small working group, and it is anticipated that a final draft of the test code will be ready for submission in June.

Aircraft Electric Control and Protective Devices. This subcommittee will be unable to complete its assignment until the guide report on systems and the work on cables has been more nearly completed.

Aircraft Wire and Cable. This subcommittee has sponsored manufacturers' tests on AN-16 and AN-8 aircraft cables and has extended the data to cover the complete range of sizes from AN-22 to AN-00. Tentative recommendations for extreme ratings of cables have been prepared as a technical paper, "Short-Time Current Ratings for Aircraft Wire and Cable," by P. W. Jones and J. A. Scott. At present further action to be taken by this committee has not been determined, and the personnel on this committee has been especially affected by reconversion resulting from the end of the war. A possible course of action will be to issue the essential content of the Jones-Scott paper as a preliminary report for trial.

Two additional subcommittees were formed during the year:

Joint Subcommittee (Air Transportation and Electric Machinery) on Carbon Brushes. The assignment of this subcommittee was the formulation of an AIEE test code for the evaluation of carbon brush performance on all types of commutators and collector rings, so as to provide for improved specifications and standards for carbon brushes used on electric machinery.

Subcommittee for Altitude Ratings. This subcommittee has been assigned the task of developing an AIEE Standard outlining the basic principles of altitude rating on electric machinery. The work will be co-ordinated with that being done by AIEE standards co-ordinating committee 1 and with Section I-12 of AIEE Publication 1.

One committee meeting, held during the winter convention, was devoted largely to consideration of the standardization activities enumerated. There was considerable discussion of a proposal to undertake a study of safety considerations affecting the use of electric equipment on aircraft. The majority of the committee expressed a desire for a preliminary review to determine the propriety of such a study. There was a strong minority opinion that this study would not come within the assigned scope of the air transportation committee. Subsequent attempts to carry out the majority sentiment of the committee have met with little enthusiasm, and the entire project now appears to be more suitable for action by the Civil Aeronautics Authority rather than by the Institute.

The committee also decided that there would not be any need to establish a proposed subcommittee to be of concern with the problems of airline operators. It was felt that this subject could be handled satisfactorily within the new Air Transportation Association

During the year a total of 17 technical papers were sponsored by the committee. Seven of these were presented in two air transportation sessions at the winter convention, and the other papers were printed and circulated for written discussion in accordance with the Institute arrangement during the cessation of meetings.

COMMITTEE ON AUTOMATIC STATIONS

The members of this committee have continued their activities in bringing to the Institute papers dealing with subjects related to automatic stations and supervisory control. Several papers were presented during the year, and additional papers have been secured for future presentation.

Two meetings of the committee were held during the past year, one in October 1945, and one in January 1946. In addition to considering material for new papers, the committee completed its plans for conferences on automatic or supervisory control of air switches and automatic control of capacitors. Authors have been secured for papers for these conferences. Being mindful of the importance of joint co-operation with other committees, careful consideration has been given to the reports of our representatives on other committees and to the work being done by our members on several joint subcommittees.

During the past year, two working groups were organized and at present are engaged actively in their assignments. One of these groups is investigating the matter of the type of trip to be provided for circuit breakers with special reference to their application to automatic stations. The other group is looking into the correct polarity of d-c control for automatic stations. The work of these groups has been well begun but will not be completed during the present fiscal year.

COMMITTEE ON BASIC SCIENCES

The committee on basic sciences sponsored the symposium on nuclear energy at the winter convention, and has arranged for a session for the summer convention. During the war, the work of the committee fell off, but recently it has begun to approach its prewar level, and technical programs for future meetings appear more promising.

At a meeting of the committee held during the winter convention, there was a serious discussion of the place of basic science material in the AIEE meeting and publication programs. The committee thought there would be a gain in reversing the apparent tendency of recent years to have material handled by committees with specific fields rather than by the committee on basic sciences, and also thought that an over-all increase in basic science material was desirable. To this end an aggressive campaign is being started to expand the work of the committee. Results probably will not show for some time, but it is hoped that the contribution will be evident in expanded technical presentations of the committee at later dates. Concurrent with the extension of the committee's activities, a group of subcommittees, the existence of which was not warranted during the war, is to be instituted.

COMMITTEE ON COMMUNICATION

More than 40 papers on a wide variety of communications subjects were sponsored by the committee during the year.

In view of the cancellation of the summer and Pacific Coast technical meetings, some of these papers were made available in pamphlet form for discussion by mail in lieu of formal presentation. These included a comprehensive report on the

January 1945 conference on radio frequency cables made up of 17 papers on the general subjects of polyethylene insulation for high frequency cables, cable manufacture, cable design, and cable testing. In addition the summer and fall technical paper program (presented by mail) included papers on judging mica quality, optimum air gap for coils subject to direct current, radio noise meter calibration and methods for measuring the attenuation of coaxial cables.

At the winter convention in January of this year, there were five communications sessions as follows:

A General Communications session which included seven papers on a wide variety of subjects as follows: electronic regeneration of telegraph signals; two papers on filter design, one for telegraph and the other for broad band carrier; two papers on throat microphones covering design and methods of testing; the solution of transmission line problems; applications of thin permalloy tape in wide band transformers, a technique which should be of interest to many as the field of wide band transmission expands.

Two Sessions on Radar which were arranged in cooperation with the committee on electronics. These sessions provided a well-rounded coverage of the radar field. The six papers presented related to general principles, two typical wartime uses of radar, two proposed peacetime uses, on ships and airplanes, and a comprehensive coverage of radar testing techniques. The latter paper should be of interest to many outside the radar field, since many of these techniques will be useful in the expanding fields of high frequency transmission and electronics.

A Session on Sound Recording and Reproducing which included eight papers on various recording media such as tape, wire, and disks. There is a growing interest in wire recording, and this was well covered by four papers relating to the general principles, a specific design of a recorder head, means for measuring the magnetic characteristics of recording wire and signal and noise levels encountered in tape recording. Two papers were presented on disk recording, one of them relating to a new reproducer design and the other to new tools for the study of disk recording performance. The growing importance of recording in business was brought out by a paper on this subject.

A Conference on Slow Acting Relays which included four prearranged talks by engineers active in this field. These covered the historical aspects, underlying electromagnetic concepts, operational features, and limitations of relays in power communication. It is planned to explore this field further with the thought of ultimately making available published material for the benefit of the entire membership.

Meetings of the committee on communication were held in June, October, and January. Indicative of the broad scope of the activities of the committee are the following subcommittees which now are functioning: sound recording and reproducing, slow acting relays, hearing aids, testing of telephone transmitters and receivers, power line carrier, underwater sound developments. These subcommittees have been active in arranging for papers in their fields, many of which were presented at the last winter convention. In the coming year, it is proposed to increase the committee activities in the field of television.

The committee has co-operated with the other technical committees wherever the subject matter was of joint interest. This is illustrated by the joint sponsorship with the committee on electronics of the papers on radar and also by the appointment of the chairman of the subcommittee on power line carrier as the committee representative on the joint subcommittee on power system applications of carrier current.

Emphasis has been placed on making available the results of the committee's activities to the entire Institute membership rather than only to the few who can attend national meetings. Substantially all of the talks presented at the various national technical meetings have been or will be published in *Electrical Engineering* or in *Transactions*. A report on the conference on high frequency cables was made available in pamphlet form, and the entire membership was notified of its availability. Also outstanding papers presented at District meetings are being recommended for publication, so that the entire membership can benefit from these papers which would otherwise be heard by only a few.

COMMITTEE ON EDUCATION

The committee on education shares with the Society for the promotion of Engineering Education and ECPD an interest in the guidance and selection of students and their proper professional education in colleges and universities offering accredited curricula in electrical engineering. It has the opportunity of co-operating with many groups within the AIEE organization to further the education of the electrical engineer, both before and after his graduation from college—indeed, to make education a continuing process in the life of each AIEE member. Its relationship to the committee on Student Branches is necessarily close. In promoting educational work in the AIEE Sections throughout the country, it works with the Sections committee. The publication of general technical articles which start from basic principles and bring the reader up to date on a particular device requires co-operation with the editor of *Electrical Engineering*.

Every year many suggestions for educational activities on the part of the Institute are received by the committee and tabled because: other agencies for the objective are already in existence, lack of funds, or inappropriateness. This year, for example, the committee did not act favorably on a proposal to establish an agency at AIEE headquarters to counsel returning veterans as to educational preparation for electrical engineering, nor did it feel that a proposal to set up a series of correspondence courses of a refresher type or on new developments in electrical engineering for returning veterans and reconverted war industry workers was feasible.

As an aid to schools teaching electrical engineering during the past year, the committee collected information on the teaching of electronics as a service course to students with a background of physics, other than electrical engineering students and has in preparation a summary of the practices reported as successful.

At the 1946 winter convention, the committee organized a session devoted to a comparison of the achievements of electrical engineering graduates in civilian war research agencies as compared with men who were professional physicists. This meeting and the full report of it published in *Electrical Engineering* may have helped considerably in clearing up a confused situation which might have done harm had it long continued.

In keeping in touch with developments in electrical engineering curricular changes, the committee has not taken any stand on their merits. The five-year program leading to the bachelor's degree has been discussed, and the experiment encouraged, with the thought that the results be reported, evaluated, and disseminated to all schools.

The place of electronics in the postwar electrical engineering curriculum will be the subject of a conference at the 1946 summer convention.

In co-operation with the committee on Student Branches, a revision of the AIEE guidance pamphlet, "The Electrical Engineer," is now in preparation, as the first edition nearly has been exhausted.

An exploration of the possibilities of standardization of laboratory equipment for schools in order to reduce costs is being undertaken.

Advisory services to Sections of the Institute contemplating the establishment of educational courses have been rendered and a joint letter sent out by the chairman of the Sections committee on this topic.

Steps are being taken to secure a new series of articles for publication in *Electrical Engineering* similar in general to those published ten years ago, which will bring AIEE members up to date on the newer developments in our field, particularly in fundamentals, written for the ordinary engineer and free of unnecessary mathematical obfuscation.

The project to revise and bring up to date the committee's list of film strips and motion pictures has been held up by unsettled conditions, but it is hoped some progress on this may have been made by the end of the year.

COMMITTEE ON ELECTRIC WELDING

A meeting of the committee was held January 21, 1946, during the winter convention. Papers for the summer convention and for the 1947 winter convention were discussed. The work being done by the technical activities subcommittee and the professional activities subcommittee was reviewed. Considerable interest was shown in the activities of these two subcommittees, and several suggestions were made which were passed on to the subcommittee affected.

There were no activities of this committee on standards, although it is understood that revision for peacetime use of war Standard C52.4, C52.5, and Z49.1 will be started in the near future. Representatives of this committee will assist in this work.

One technical session was sponsored by the committee at the winter convention. Four technical papers were presented. Two of the papers were on arc welding subjects, and the other two were on resistance welding. Two technical sessions are being sponsored at the summer convention. Three technical papers and one

conference paper are to be presented on resistance welding subjects, and three conference papers on arc welding subjects.

COMMITTEE ON ELECTROCHEMISTRY AND ELECTROMETALLURGY

The activities of the committee on electrochemistry and electrometallurgy during the past year have been confined largely to subcommittee work. No sessions or conferences have been sponsored at any of the national or District meetings. A meeting of the committee was held in New York, January 24, 1946, at which the work of the subcommittee was reviewed and plans formulated for future activities.

The subcommittee on metallic rectifiers, under the chairmanship of Doctor L. O. Grondahl, is actively at work on the following projects:

(*a*). Preparation of a test code.

(*b*). Preparation of a list of nomenclature and symbols.

(*c*). Preparation of a bibliography on metallic rectifiers.

Preparation of the bibliography is nearing completion, and excellent progress is being made on the test code and nomenclature. A group to consider the preparation of standards also is contemplated. Four meetings a year are planned by this subcommittee. The first was held in New York, January 25, 1946, and the second is scheduled to be held April 25, during the North Eastern District meeting in Buffalo.

The subcommittee on voltage transients in arc furnace circuits of which Doctor E. R. Whitehead is chairman, held a meeting in New York on January 23, 1946. Doctor Whitehead presented a report on the 1945 trouble record for arc furnace customers on the Duquesne Light Company System. Among 29 customers having 44 arc furnace installations, there were 18 reported cases of trouble. Of the 18 cases of trouble, possibly three, and probably one, were caused by overvoltage.

In a discussion of the most fruitful course of future action, S. B. Griscom suggested that the subcommittee prepare a brief report outlining preferred practice in arc furnace installations. It was pointed out that such a report would not be considered a standard and that similar guides had proved very useful in other fields. A preliminary outline of subjects to be considered was drawn up, and a working group has been appointed to prepare a first draft before June 1.

The subcommittee urges all who may have test data, or any information on this subject not included in the 1944 report, to assist in this work, either by the preparation of an appropriate technical paper or by submitting it to the committee for discussion.

The committee on electrochemistry and electrometallurgy also is represented on the joint subcommittee on induction and dielectric heating.

COMMITTEE ON ELECTRONICS

The subcommittee plan of operation is employed for the work of this committee. A meeting of subcommittee chairmen was held in October 1945, and another in April 1946, both in New York. A meeting of the entire committee was held during the winter convention.

Subcommittee activities have been as follows.

1. Electronic Power Converters Subcommittee. This group has during the past year completed two tasks that have been in process for several years, and represent the result of a great deal of effort on the part of each of many subcommittee members.

The first of these is a draft of "Standards for Pool Cathode Mercury-Arc Power Converters," which is now in the hands of the standards committee. Copies of this draft will be distributed broadly to encourage early use of the proposed Standards. It is planned to publish a review of these Standards in *Electrical Engineering* at an early date, and to provide an opportunity for discussing them at the summer convention.

The second of these two completed tasks is a report on "Inductive Co-ordination Aspects of Rectifier Installations." It is planned to present this for discussion during the summer convention, and to publish it in *Electrical Engineering* and the *Transactions*.

Work on a bibliography covering electronic power converters is approaching completion. Tasks that lie ahead for this subcommittee are the preparation of standards for electronic power converters employing hot cathode tubes and standards for electronic power converters used with electronic motors.

2. Subcommittee on Nomenclature, Definitions, and Symbols. This group has completed the preparation of an extensive set of proposed standard definitions, which are being channelled through the standards committee for adoption. An important aspect of this work has been co-ordination with a similar IRE activity. Additional work is in progress extending the coverage of the standards proposals to additional subject matter.

3. Technical Papers Subcommittee. This subcommittee generally has encouraged and solicited the preparation of technical papers on electronic subjects. The policy of distributing available papers on electronics to other committees which sponsor sessions covering the applicational subjects involved has been continued. The technical paper coverage of electronic subject matter has been in general satisfactory.

This subcommittee organized and conducted a very successful informal technical conference at the winter convention. The subject was "New Industrial Uses of Electronics Resulting from Wartime Developments." Additional similar future programs are being planned.

In response to a request for help in carrying on the work of technical groups affiliated with local Sections, manufacturers of radio and electronic equipment were canvassed for movie films, lecturers, bulletins, educational courses, and the like, and the material so collected was correlated and distributed to local Sections.

4. Subcommittee on Electronic Heating. By means of approximately monthly meetings throughout the winter and spring, this subcommittee has been very active in the difficult work of promoting co-ordination of electronic heating practices with Federal Communication Commission's frequency allocations and radiation field strength limitations. This group also has given attention to safety practices and equipment rating standards.

5. Electron Tube Subcommittee. This group has undertaken a program of gas tube standardization work in close co-operation with a parallel group in the IRE.

6. Liaison Subcommittee Activities. There is a general need for improving the co-ordination between technical activities in electronics of the AIEE committee and certain parallel activities of the IRE and related activities of the Joint Electron Tube Engineering Council (JETEC), also for effective contact with the AIEE Standards committee and the American Standards Association. To this end, there have been established, under the committee on electronics, a subcommittee on JETEC liaison and tube standards, a subcommittee on AIEE-IRE liaison, which has become active in discussions toward standardization of frequency-band nomenclature, and a subcommittee on electronic standards. These subcommittees have been active in various technical and co-ordination problems.

7. Other Subcommittees. Subcommittees on electronic precipitation, electronic control, electronic welding, X-ray tubes, and on wires and cables, have been active in their respective fields. The committee on electronics thinks that one of its important responsibilities is to serve as a continuing co-ordinating agency between the various professional organizations in the electronics and technical workers in various differing applicational fields where the use of electronic devices is important.

COMMITTEE ON INDUSTRIAL CONTROL DEVICES

This new committee was organized in the fall of 1945. Three meetings have been held. The first, or organizing meeting, was held in Milwaukee on November 7, 1945, and the second meeting was held in New York on January 21, 1946, during the winter convention. The third meeting was held in Cleveland on April 11, 1946, and a fourth meeting is scheduled to take place in Detroit during the coming summer convention.

Considerable discussion has dealt with the scope of this new committee in its relation to other committees of the Institute. In order to pursue its work, the following subcommittees and working groups have been set up:

1. Subcommittee on industrial electronic control. This subcommittee will work in co-operation with a subcommittee of the committee on electronics.

2. Subcommittee on revision of AIEE–ASA Standards 15.

3. Subcommittee on test codes for industrial control devices.

4. Subcommittee on servomechanisms.

5. Liaison with American Society for Testing Materials.

6. A working group on bibliography on industrial control.

A number of papers have been reviewed in preparation for presentation at coming Institute conventions.

COMMITTEE ON INDUSTRIAL POWER APPLICATIONS

Owing to conditions prevailing last year, this committee carried on practically no work after the winter convention of January 1945 until the present committee was formed last September.

At the January 1945 meeting, a series of papers and very interesting discussions on the subject of industrial voltage requirements were presented, although the subject was found to be too broad to reach any conclusions at one session.

When the present committee took up the work last September, it decided to form two subcommittees, one to study again the subject of industrial voltage requirements, and the other to review the field of machine and process drives.

At the winter convention, in January 1946, the committee sponsored three sessions, two covering chiefly the industrial voltage subject, and one on co-ordinated drives in industrial processes.

The two sessions on industrial voltage requirements were held on the same day, and a committee luncheon meeting was held between the two sessions.

At the first session, an interim report on the subject of industrial voltage requirements was presented, and was very well received. A number of good suggestions were received from the discussion from the floor. Therefore, the subcommittee is at present actively working and hoping to present a completed report on this subject in the near future for review by the board of directors.

The committee luncheon was attended by 22 members of the committee and the major topic of discussion was a continuance of the subject industrial voltage requirements. It was the concensus that this subcommittee should continue the work and have a final report available at the earliest possible date.

The second session, held in the afternoon of the same day, was sponsored jointly by the committee and the inductive heating subcommittee. Two papers were given on subjects allied to industrial voltage requirements and two papers on inductive heating.

The third session was under the auspices of the subcommittee on machine and process drives. A general report outlining the proposed scope of this subcommittee was presented, and the discussions from the floor suggested that the work of this committee should stress the increasing importance of co-ordinated drives in industrial processes.

Two papers were presented on allied subjects which were well received, and committee members expressed a desire for more papers along the lines of the two that had been given which furnished technical and practical application data on co-ordinated drives.

This subcommittee held a meeting in March, when it was agreed by the membership that better results might be obtained by sponsoring papers for a particular industry at two or three of the main technical meetings throughout the year and by ultimately assembling the best of the papers presented into a report form. It was agreed that at the next main technical meeting the subcommittee would have available a series of papers covering the textile industry.

The committee members, both at the winter convention and at the various subcommittee meetings, have agreed to try to cultivate the interest of the industrial groups of all sections of the Institute. By this means we are hoping to build a closer tie between the national committee and the various industrial groups, thereby creating greater interest throughout the membership of industrial problems.

COMMITTEE ON INSTRUMENTS AND MEASUREMENTS

With the cessation of hostilities, the committee on instruments and measurements resumed many activities curtailed during the war and has undertaken a number of new projects. Two meetings of the committee were held in New York, one November 14, 1945, and the other April 10, 1946.

Although no technical meeting was held during the summer, the committee reviewed a considerable number of technical papers, and four were included on the summer technical program. Gyroscope testing, resistance thermometers, lag of thermometer elements, and current transformers were subjects of the papers. At the winter convention in January 1946, seven papers were presented in two sessions under the sponsorship of the committee. The papers covered a wide range of instrument and measurement applications, including stress measurement, servomechanisms, surge-current measurement, high-speed recording, thermal demand meters, and automatic oscillography. The sessions were well attended, and a great deal of interest was shown in the papers. Through the year a number of papers reviewed by the committee were included on the programs of District or Section meetings. Three sessions under sole sponsorship of the committee or joint sponsorship with other committees are planned for the next summer convention.

Through its 14 subcommittees, the committee has been active in standardization matters. Preliminary drafts of master test codes for resistance measurement and for temperature measurement have been prepared, and now are being considered for approval by the main committee. A proposed final draft of the revision of a former report on a proposed Standard 40, on recording instruments, is nearing completion and is expected to be ready for recommendation as a new standard in the next few months. Recommended changes in and additions to the "American Standard Definitions of Electrical Terms" are under preparation and will be offered as suggestions for a future revision of that Standard. A revision of the 1941 AIEE report on "Telemetering, Supervisory Control and Associated Circuits" is being undertaken by the joint subcommittee on that subject.

In co-operation with the corresponding subcommittees of the ASA sectional committee C-57, and of the committee on protective devices, the subcommittee on instrument transformers has carried forward the work on the instrument-transformer definitions to be included in the ASA Standard on transformers. A request of the committee on instruments and measurements that the section of this standard dealing with instrument transformers be separated editorially from the complete standard has received favorable consideration by the ASA committee, and the subcommittee on instrument transformers plans to carry out the editorial work necessary to make the separate publication possible.

The field of servomechanisms has received particular attention during the past year, and the subcommittee on that subject has been active in stimulating papers on servomechanisms and in sponsoring, jointly with the corresponding subcommittee of the committee on industrial control devices, a session on servomechanisms at the coming summer convention.

Because of the growing importance of electronic instruments in a wide variety of instrument and measurement applications a joint subcommittee on electronic instruments has been formed through co-operative action by the committees on instruments and measurements and on electronics. This subcommittee is engaged actively in stimulating papers and discussion on electronic instruments for a conference at the summer convention

COMMITTEE ON MARINE TRANSPORTATION

The printed revision of Standard 45 became available during February 1946 as the 1945 revision of the Standard.

It was considered inadvisable to hold meetings of the committee until the printed revision was available. Therefore, no meetings were held during latter part of 1945.

Two all-day meetings of the committee were held during 1946, and it is proposed to have one more all-day meeting before the close of the administrative year. Discussions at these meetings cover preparation of proposed changes and additions applicable to future revisions of Standard 45.

The committee believes that future revisions of Standard 45 should include complete recommendations covering a-c installations. This action is deemed advisable because of the increased use of a-c distribution systems on ships together with the greatly increased number of electrically propelled vessels.

There have been no changes in the personnel of the committee except the addition of one AIEE member, a British electrical engineer, prominently identified in similar activities in British Institution of Electrical Engineers. It is believed that this addition to our membership will make for closer relations between American and British shipboard electrical practices.

COMMITTEE ON POWER GENERATION

In spite of rather severe handicaps imposed by the war and by the subsequent dislocations, the first year of the activities of the committee on power generation, while operating with the newly appointed and expanded subcommittees, proved to be quite successful. The response of the membership to the plans and efforts of the committee has been very satisfactory, and there is every indication that the committee will continue to grow in its importance.

The specific activities of the committee during the past year may be summarized as follows:

Central Station Auxiliaries. The material of the previously held technical conference on the subject of central station auxiliaries had been rewritten in the form of five technical papers, subjected to the regular review and grading, and finally published as a part of the 1945 fall technical paper program. The comments and discussions received since the publication indicated that this activity served a timely and useful function.

Hydroelectric Systems. It has been realized for some time that the problems of the design and operation of hydroelectric systems did not receive sufficient attention in the technical activities of the AIEE, as compared with their importance in the electrical picture in this country. Under the sponsorship of a newly appointed subcommittee, a thorough canvass was made of the potential interest and possible material pertaining to this topic.

The initial session on hydroelectric systems was held during the 1946 winter convention in New York, with the presentation of two technical papers and three conference papers. There was evidence of a strong interest on the subject especially among AIEE Canadian membership. Present plans call for the continuation of this activity with a sponsorship of similar sessions at the summer convention in Detroit, at the winter convention in New York, and possibly at the Pacific Coast convention.

Excitation Systems. Another new activity of the committee, originated this year and introduced to the membership with a symposium of six papers at the 1946 winter convention, was the subject of excitation systems. The excellent attendance of the session and the widespread discussion of the topic indicated that this activity also meets a real need and that it should be continued. Accordingly, the subcommittee made plans for further contributions at the summer and winter conventions. Work is in progress to formulate definitions and terms used in discussions of excitation systems.

Prime-Mover Governing. The present activities of this subcommittee are:

1. A revision of AIEE 600 relating to speed governing specifications for steam turbine generators.
2. The preparation of a specification for the speed governing of hydro turbine generators.
3. The preparation of two additional specifications for types of steam turbine generators not covered under AIEE 600.

The probability is that all work in progress will be completed and submitted to the standards committee for approval by the spring or summer of 1947.

COMMITTEE ON POWER TRANSMISSION AND DISTRIBUTION

A full meeting of the committee was held at the winter convention. A report was made by a subcommittee consisting of the officers and chairmen of subcommittees on possible reorganization of committees. The only change proposed and approved by the main committee was to change the three working groups under the transmission subcommittee to full subcommittees to be known as lightning and insulator subcommittee; towers, poles, and conductors subcommittee; and insulated wire and cable subcommittee. The change will take place at the beginning of the next administrative year.

Technical Meetings. At the winter convention, the committee sponsored one technical meeting. A report of the lightning and insulator working group on the "Lightning Performance of 220-Kv Lines—Part II" was made. Other papers dealt with economics of transmission, arcing grounds on 13-kv, 3-phase busses, and inductance of square busses.

Subcommittee Activities. The distribution subcommittee has a joint project with the relay subcommittee of the committee on protective devices through a working group composed of members of both subcommittees. This group is studying plans for improvement in the quality of service on overhead distribution circuits. Also a study is being made of proper forms for reporting the troubles on distribution circuits to obtain better evaluation of the effects of different construction practices and protective devices. The group has had one meeting and plans another during the summer convention. The subcommittee is canvassing its members for possible papers for the winter convention in 1947. This subcommittee has under consideration the following subjects: (*a*) design of systems for fluctuating loads; (*b*) 4 versus 13 kv distribution economics; (*c*) network supply from two sources; (*d*) nonleaded cables in the earth.

The stations subcommittee held one meeting and has arranged for papers to be presented at a session during the summer convention.

The transmission subcommittee, through the working group on lightning and insulators, presented its report on the questionnaire on lightning performance of 190 to 287-kv lines by means of a paper at the winter convention in January 1946. This group is now preparing a second volume of the "Lightning Reference Book" to cover the period from 1935 to 1945 inclusive. This working group has under consideration the following projects: (*a*) the predetermination of lightning performance of transmission lines as a guide to the design of such lines; (*b*) a questionnaire on the record of outages on high voltage lines from all causes; and (*c*) a survey of the performance of insulators, wood and air in series, and possibly a further investigation of the subject. It is expected to have two papers available for the summer convention dealing with ceramic dielectrics at elevated temperatures and co-ordination of insulation and spacing of transmission line conductors.

The cable working group has interchanged correspondence on the beginning of a study to investigate the proper methods for evaluating the effect of the thermal properties of buried cable systems of the direct burial and duct types. The group has been actively soliciting papers, so that it is expected to have six papers at a cable session to be held at the summer convention. There are also prospects for about five papers at the winter convention in 1947. The working group on towers, poles, and conductors has been endeavoring to get papers on the comparison of wood and steel in structures and on the preservative treatment of wood. There is a possibility of one paper for the summer convention.

The general systems subcommittee is studying a standard method of evaluating power losses, which it is hoped will result in two papers. The subcommittee is still studying stability of transmission lines, which study will continue for another year or two. The subcommittee is following the development of d-c transmission both in Europe and in the United States. The subject of overvoltages on transmission lines is under consideration by the subcommittee.

It is intended to have a meeting of the full committee during the summer convention in Detroit. The committee is sponsoring two sessions at this convention.

COMMITTEE ON PROTECTIVE DEVICES

Principally because of the wide variety of fields included in the scope of the committee, an attempt was made this year to place more of the responsibility for the preparation of Standards and other specific activities in the hands of the subcommittees rather than attempt to cover too many of these details in the main committee. The subcommittees have reacted favorably to this increased responsibility, and, with a few more adjustments necessitated by this change in operating concept, they should be able to function very satisfactorily.

The committee sponsored 13 papers for the winter convention and expects to have about 8 on the schedule for the summer program. A special working group has been set up to solicit papers by operating engineers. It is thought that particularly in the postwar period a review of operating experiences can be of major assistance to

the manufacturers in formulating plans for new designs and new products. It is recommended that this activity be continued at least for the coming year.

There have been two meetings of the main committee and another is scheduled at the time of the summer convention in Detroit. The subcommittees have met more frequently, and their accomplishments outlined in more detail follow.

Circuit Breakers and Assembled Switchgear. The work of the subcommittee was handled mainly through six working groups, each of which was assigned a specific project.

The working group on the "Air Circuit Breaker Standard 20" completed the work on the proposed Standards and have referred it to the committee for further action.

The working group on "Switchgear Assembly Standard 27" reviewed the standard in its present form and decided that no further action should be taken this year.

The working group on the proposed standards for automatic circuit reclosers for a-c distribution circuits sent out drafts of the proposed standards at two different times. Adverse comments were received on both drafts, and the project will require further action by both the working group and the subcommittee. For this purpose, it is planned to hold a joint subcommittee and working group meeting in Pittsburgh on May 16. It is hoped that at that time the differences of opinion which have prevented passing of the standards can be cleared and that the standard can be presented to the committee for final action before closing the current year's business.

The working group on studying short-circuit current for low voltage circuits has held several meetings, but was unable to complete its work until more test data could be obtained and examined. Their work is not expected to be completed this year.

The working group on "Power Circuit Breaker Standard 19," which was assigned the additional problem of studying the method of defining interrupting ratings, reports satisfactory progress, but states that its project cannot be completed during the current year. No revision of Standard 19 is recommended at this time.

The working group on technical program papers by operating engineers has worked diligently to obtain papers covering operating experiences. The reward for its interest has been slight and not all that was hoped for.

It is recommended that the work of the group on the method of defining interrupting rating should be continued into the succeeding year or until it is completed. The matter of technical program papers by operating engineers should be an item for continuing study. Although the results obtained have not been very satisfactory, it is believed that the interest of the Institute demands that study of the subject should be continued until satisfactory results are obtained.

Lightning Protective Devices. "Expulsion Type Distribution Lightning Arresters, AIEE Standard 47," December 1945, was sponsored by H. L. Stewart, New England Power Service Company. His working group completed the Standard except for editorial changes during 1945. The Standard was issued for trial use December 1945. The project has been completed.

"Industry Survey of Performance Characteristics of Distribution Expulsion Type Lightning Arresters" was sponsored by E. W. Beck, Westinghouse Electric Corporation, East Pittsburgh, Pa. Mr. Beck appointed a working group and secured data from all manufacturers of these arresters, worked up a first draft of the report, then submitted it to the group for comments. Comments and new data were received which required a new draft. The new draft will be submitted to the working group for approval when completed, after which it will be sent to the subcommittee for approval and publication in *Electrical Engineering*. It is suggested that this project be continued to completion under the sponsorship of Mr. Beck.

"Survey of Lightning Protective Equipment Used on A-C Rotating Machines" was sponsored by T. H. Mawson, Commonwealth and Southern Corp., Birmingham, Ala. Mr. Mawson prepared a questionnaire which was sent to major utilities. Complete returns are not in. It is suggested that this project be continued under the sponsorship of Mr. Mawson.

"Lightning Protection for Substation Units" has been sponsored by E. R. Whitehead, Duquesne Light Company, Pittsburgh, Pa. Mr. Whitehead appointed a working group and set up the following procedure:

(*a*). To formulate the problem more definitely.

(*b*). To contact the transformer subcommittee with a view to having them co-operate in this study.

(*c*). To consult with manufacturers to get their views on the protection needed in the problem.

It is suggested that this project be continued under Mr. Whitehead's sponsorship.

Combination of the three Lightning Arrester Standards, AIEE 28, 47, and 24 was sponsored by F. M. Defandorf, National Bureau of Standards, Washington, D. C. He appointed a working group and has issued a second draft which is now in the hands of the working group for comments. Mr. Defandorf has made an excellent start on this project and is doing a splendid job. It is therefore suggested that this project be continued under his sponsorship. This is a major standard and may require several years to complete, as there is considerable revising to be made in the test sections which require new information.

The subject of surge protection for arc furnaces was discussed by the committee. Mr. Whitehead, chairman of the subcommittee on overvoltages in arc furnace circuits, was asked to serve as the contact between the two committees and offer the assistance of the lightning protective devices subcommittee. No working project has been set up for this subject, as the need for such a group has not crystallized.

Fault Limiting Devices. This subcommittee has had three active working groups on present-day grounding practices; revision of "Standard 32, Neutral Grounding Devices"; and "Bibliography Concerning System Grounding." This latter group was formed January 23, 1946. The series capacitor protective device has been assigned to this subcommittee, and one paper on this subject was presented at the January meeting. The subcommittee will be prepared to sponsor standards in connection with these devices if necessary.

Relays. Two meetings of the relay subcommittee were held, one in Cleveland, October 18, 1945, and one in New York, January 21, 1946. Another meeting of the subcommittee to summarize the activity of the year will be held in Cleveland, May 16.

As in recent years, the work of the subcommittee has been carried forward principally by a number of working groups, to each of which has been assigned a particular project.

A working group on the bibliography of protective relaying has been continued, and has prepared a bibliography of technical articles on relaying for 1945. The sponsor of this group is again C. E. Parks. The bibliography for 1945 was distributed not only to the members of the subcommittee, but also to the relay subcommittee mailing list, a list prepared by the subcommittee of approximately 100 engineers who are most vitally interested in relaying problems. As this bibliography is now kept up to date year by year, it will be a simple matter to publish the accumulated bibliography for a period of three or four years, whenever it becomes desirable. It is recommended that the work of this group be continued.

A working group under the chairmanship of J. C. Bowman has continued to study the protection of generators against winding failures. It is anticipated that this group will prepare a report on recommended practices for relay protection of generators, which should be published when completed. The activity of this group should be continued until a report is published.

The working group on current transformers with low-current secondary windings has been continuing, but S. C. Leyland has taken over the sponsorship. A report covering various applications justifying the use of current transformers having a rated secondary current of less than 5 amperes is being completed, and it is hoped that this report can be presented at the summer convention in 1946.

The activity of the working group on the protection of power house auxiliaries, sponsored by E. L. Michelson, is drawing to a close, and the report of this work, including recommended practices, will be presented at the summer convention in 1946. A preliminary report was presented for discussion at a conference on relaying problems held at the winter convention of the AIEE in January. The work of this group should be complete this year.

The working group on the co-ordination of transformer protection, organized last

year, has continued to study these problems, with W. R. Brownlee as sponsor. A preliminary report and a conference paper on the work of this group were presented at the conference session on relaying problems at the winter convention, and the discussion provided additional material for work of the group. It is expected that a final report can be prepared for the winter convention in 1947, and the group should be continued until the report is presented.

The group on standards for instrument transformers for relaying purposes has been continued under the sponsorship of C. A. Woods. The principal activity of this group, which consisted in assisting subcommittee 4 of ASA committee C57 to revise the American Standards for instrument transformers, has been completed, but some additional work on guides for operation and the test code for instrument transformers has remained for further consideration. This group should continue to stand by until all details of the revision of ASA C57 have been completed, but no further extensive activity is contemplated in the near future.

A joint working group with the committee on power transmission and distribution was appointed last year to study the correlation of construction and protection of distribution circuits, with George Dodds as sponsor. Because of the joint sponsorship, some delay was experienced in completing the organization of this group, but activity is continuing, and the first meeting of the entire group was held in Pittsburgh, March 20. The activity of this group should continue throughout the next year and should result in a valuable report on distribution circuit problems.

During the year a working group was appointed to carry out the revision of ASA Standards for protective relays, under the sponsorship of J. H. Oliver. Because of man power limitations, this group has not yet been very active, but has been studying the problem, so that when man power is available the work can proceed rapidly. The activity of this group is being co-ordinated with the corresponding subcommittee of ASA committee C37 on power switchgear, so that the completed draft of the proposed revision may be acceptable without extensive change as the ASA Standard. The work of this group should continue until the new standard is accepted and published.

A working group under the sponsorship of H. R. Paxson has been investigating the problem of grounding instrument transformer secondaries. A considerable divergence of practice was found, and it appears desirable that a report on this subject should be presented to the Institute. Possibly this report may be ready for the summer convention in 1946, but in any case it should be ready by the time of the winter convention in 1947.

COMMITTEE ON APPLICATIONS OF ELECTRICITY TO THERAPEUTICS

This committee held one meeting during the year. At this meeting, the following general principles were considered.

There are three factors in the application of electricity to human beings:

(a). The effect, if any, on man.

(b). The safe limits of dosage, and the measurement of the same.

(c). Methods of protecting the operator.

The following applications were considered.

1. About high frequency of heating, it was the general opinion of the committee that workers could be shielded from high frequency fields by interposing metal barriers. There is no information available as to the amount of heating to which a human being could be subjected without injury.

2. It was brought to the attention of the committee that some of the ultrahigh frequencies used in radar produced a certain amount of X-ray radiation. Most of this is believed to be in the soft X-ray field. It is claimed, however, that some very hard X-rays may be produced. The committee has suggested that a study be made and the amount of X-ray radiation produced by different radar sets be investigated.

3. The effect of sun lamps and ultraviolet-ray radiation lamps also was discussed. A few individuals are believed to be supersensitive to such radiation. The Westinghouse Electric Corporation volunteered to furnish equipment and lamps and to help in carrying out a study of the amount of ultraviolet radiation. The School of Hygiene at the Johns Hopkins University was suggested as a possible location for carrying on this investigation. It has been notified of the project, and it is under consideration.

4. Doctor Rentschler of the Westinghouse Electric Corporation called attention to a special short wave lamp and its successful use in treating infected wounds. He reported that certain deep-seated wounds which had not responded to sulpha treatments had healed rapidly when exposed to rays from the lamp.

Awards

INSTITUTE PRIZES

In May 1945, the committee on award of Institute prizes reported the award of three national prizes, after consideration of all eligible papers in the several classifications for prize awards and solicitation of the recommendations of the chairmen of the technical committees relative to the best papers in specialized fields. As usual, the choice between leading papers worthy of award in the several classes of prizes was very close. The committee gratefully acknowledged the assistance of the technical committees and their reviewers in nominating and grading the many papers eligible for the awards. Owing to the wartime situation, no papers were submitted for the national prize for Branch paper.

SPECIAL COMMITTEE TO REVIEW PRACTICES IN THE AWARD OF INSTITUTE PRIZES

The committee has prepared and submitted to the board of directors a proposed revised practice covering the award of Institute prizes. The suggested practices were determined after reviews with various interested committees and the vice-presidents representing the Districts. Questions related to prize award practices of the Sections have been raised by the chairman of the Sections committee, and the special committee requested that action by the board be postponed pending further consideration of the Section problem now being undertaken by the Sections committee.

EDISON MEDAL

The Edison Medal, awarded by a committee composed of 24 members of the Institute, was presented for 1945 to Philip Sporn, executive vice-president, American Gas and Electric Service Corporation, New York, "for his contributions to the art of economical and dependable power generation and transmission." The presentation took place January 23, 1946, during the winter convention. The medal may be awarded annually for "meritorious achievement in electrical science, electrical engineering, or the electrical arts."

LAMME MEDAL

The Lamme Medal committee awarded the medal for 1945 to David C. Prince, vice-president, general engineering and consulting laboratory, General Electric Company, Schenectady, N. Y., and past president of the Institute. Arrangements are being made for the presentation of the medal at the annual business meeting in Detroit, June 26, 1946. The medal may be awarded annually to a member of the AIEE "who has shown meritorious achievement in the development of electric apparatus or machinery."

HOOVER MEDAL

The Hoover Medal was established through a trust fund created by a gift from Conrad N. Lauer and is to be awarded periodically "to a fellow engineer for distinguished public service" by a board representing the ASCE, American Institute of Mining and Metallurgical Engineers, ASME, and AIEE. The seventh medal, for 1945, was awarded to Doctor William H. Harrison, vice-president, American Telephone and Telegraph Company, New York, and was presented to him on January 23, 1946, during the AIEE winter convention.

JOHN FRITZ MEDAL

The John Fritz Medal board of award is composed of representatives of the ASCE, AIME, ASME, and AIEE. The medal may be awarded annually for notable scientific or industrial achievements. The 1945 medal was awarded to Doctor Zay Jeffries, vice-president in charge of chemical department, General Electric Company, Pittsfield, Mass.

WASHINGTON AWARD

The Washington Award for 1946 was bestowed upon Doctor Vannevar Bush, president of the Carnegie Institution of

Washington (D. C.), and director, Office of Scientific Research and Development. The presentation was made at a dinner in Chicago, Ill., in February. The award may be made annually to an engineer by the commission of award composed of nine representatives of the Western Society of Engineers and two each of the ASCE, AIME, ASME, and AIEE.

ALFRED NOBLE PRIZE

This prize, established in 1929, consists of a certificate and a cash award from the income of a fund contributed by engineers and others to perpetuate the name and achievements of Alfred Noble, past president of the ASCE, and of the Western Society of Engineers. It may be made to a member of any of the co-operating societies, ASCE, AIME, ASME, AIEE, or WSE, for a technical paper of particular merit accepted by the publication committee of any of these societies, provided the author, at the time of such acceptance, is not over 30 years of age. The award for 1945 was presented, in January 1946, to A. L. Ahif, a member of the ASCE, for his paper, "Design Constants for Beams with Nonsymmetrical Straight Haunches."

CHARLES LE GEYT FORTESCUE FELLOWSHIP

No fellowship has been awarded this year on account of the fact that there are so few graduate students in the colleges at this time. Sufficient funds are available to consider the granting of fellowship awards, totaling about $1,000 per year. It is expected that as soon as there are a reasonable number of graduate students in the colleges, notices will be sent out offering this fellowship.

Joint Activities

UNITED ENGINEERING TRUSTEES, INC.

This organization manages property and funds held jointly by the four founder societies, including the Engineering Societies Building, the Engineering Societies Library, and the endowment funds of the Engineering Foundation.

The building is occupied fully by engineering organizations, and additional space is needed both for offices and for meetings. Therefore, there has been a renewal of planning for the future adequate housing for engineering societies.

The founder societies have been requested to report fully upon their present and estimated future needs for space. A committee of the UET is endeavoring to develop tentative plans for the remodeling of the building or the procurement of a new building to meet the needs of the founder societies and, if possible, bring in other engineering societies.

Increased revenue from meeting halls and close attention to expenditures produced a small credit balance for the year ended September 30, 1945.

An abstract of the annual report for the year ended September 30, 1945, appeared in *Electrical Engineering*, January 1946, page 47.

ENGINEERING FOUNDATION

The Engineering Foundation was established in 1914 as a joint organization of the four societies, ASCE, AIME, ASME, and AIEE, for "the furtherance of research in science and engineering, and the advancement in any other manner of the profession of engineering and the good of mankind."

Each research project supported by it is under the sponsorship of one of the founder societies.

During the year, the Welding Research Council continued work on nine projects and inititated two new projects. The council is sponsored by the founder societies, the American Welding Society, and the Society of Naval Architects and Marine Engineers. Its work is carried on by eight research committees.

Other reserach projects supported by the Foundation include soil mechanics, columns, alloys of iron, metal cutting, plastic flow of metals, and strength of metals.

The Foundation has continued to support the work of the ECPD.

An abstract of the annual report for the year ended September 30, 1945, appeared in *Electrical Engineering*, January 1946, pages 48–9.

ENGINEERING SOCIETIES LIBRARY

The Engineering Societies Library was formed by combining the separate libraries of the ASCE, AIME, ASME, AIEE, and preparing a composite card catalogue.

Special services rendered by the library include: photoprints, searches, abstracts, translations, bibliographies, book loans by mail.

Wartime conditions prevented the usual growth in the book collection and greatly increased the demand for photostat prints and for other services.

An abstract of the annual report for the year ended September 30, 1945, appeared in *Electrical Engineering*, January 1946, page 49.

EMPLOYMENT SERVICE

Operating as an incorporated nonprofit organization, the Engineering Societies Personnel Service, Inc., assists members of the founder societies desiring to secure new positions and employers searching for engineers. Nonmembers may receive such assistance when positions available cannot be filled by members.

Offices are operated in New York; Detroit, Mich.; Chicago; and San Francisco, Calif.; with the co-operation of the Engineering Society of Detroit in that city, the Western Society of Engineers in Chicago, and the Engineers Club of San Francisco in that city.

For several years, the service has been on a self-supporting basis, but the prevailing scarcity of engineers available for new positions has reduced the number of placements. A record of registration and placements during the past year is given in Table XII.

ENGINEERS' COUNCIL FOR PROFESSIONAL DEVELOPMENT

Organized in 1932 to engage in activities leading toward the enhancement of the professional status of the engineer, this council now includes three representatives of each of the eight participating organizations: the ASCE, AIEE, ASME, AIME, SPEE, American Institute of Chemical Engineers, National Council of State Boards of Engineering Examiners, and the Engineering Institute of Canada.

During the past year, as in previous wartime years, inspections of engineering curricula by the committee on engineering schools were held to a minimum. Twenty-six curricula in 13 institutions were inspected during the past three years. Complete regional personnel for the accrediting of technical institute curricula has been organized.

Other activities are carried on by committees whose titles indicate the nature of their work: student selection and guidance, professional training, professional recognition, information, engineering ethics, employment conditions for engineers, and ways and means.

A comprehensive report on the activities during the year ended September 30, 1945, was published in *Electrical Engineering*, December 1945, pages 461–2.

ENGINEERS JOINT COUNCIL

This Council, formerly known as the joint conference committee, is composed of the presidents, immediate past presi-

Table XII. Analysis of Employment Service

Month	Men Registered					Men Placed				
	New York	Chicago	San Francisco	Detroit	Total	New York	Chicago	San Francisco	Detroit	Total
1945										
May	101	24	40	30	195	17	8	19	10	54
June	98	30	36	24	188	20	9	24	6	59
July	92	28	37	24	181	27	20	20	9	76
August	141	54	53	39	287	20	15	15	9	59
September	242	88	92	57	479	27	25	19	8	79
October	329	79	124	73	605	35	12	20	13	80
November	226	97	113	55	491	43	20	22	11	96
December	202	67	100	43	412	36	16	20	11	83
1946										
January	338	106	134	49	627	42	27	25	13	107
February	251	86	126	60	523	28	18	19	9	74
March	296	79	182	81	638	34	18	20	13	85
April	246	98	113	65	522	43	20	24	20	107
Total	2,562	836	1,550	600	5,148	372	208	247	132	959

dents, and secretaries of the founder societies and the AIChE. Its functions are to consider matters of interest to the societies and to make recommendations to their governing bodies.

A panel was organized to advise a Senate committee regarding research legislation, and a joint committee on technological personnel in relation to national security was established.

Major projects have been started on industrial disarmament of aggressor states, economic status of the engineer, and organization of the engineering profession.

REPRESENTATIVES

A complete list of about 40 joint bodies upon which the Institute is represented appears in the Year Book and in the September issue of *Electrical Engineering* each year.

Appreciation

The board of directors expresses its deepest appreciation and thanks to the committees, and the District, Section, and Branch officers, and the members in general in grateful recognition of the many expansions in activities and the continuing rapid increase in membership.

Respectfully submitted for the board of directors.

H. H. HENLINE
Secretary

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

Securities Owned, April 30, 1946

Schedule 1

	Principal Amount of Bonds or Number of Shares of Stock	Restricted Funds: Reserve Capital Fund	Life Membership Fund	International Electrical Congress Library Fund	Lamme Medal Fund	Total
Railroad Bonds:						
Atlantic Coast Line first consolidated 4%, due 1952	$ 4,000.00				$4,253.78	$ 4,253.78
Baltimore & Ohio, Pittsburgh, Lake Erie & West Virginia System 4%, due 1951	10,000.00	$ 6,450.00				6,450.00
Chicago & Erie Railroad Company 5% first mortgage, due 1982, registered	1,000.00	1,105.00				1,105.00
New York Central Railroad Company 4% series A consolidated mortgage, due 1998	10,000.00	6,100.00				6,100.00
Northern Pacific Railway Company collateral trust 4½% due 1975	10,000.00	10,325.00				10,325.00
St. Louis-San Francisco Railway Company 5% prior line mortgage series B, due 1950 (certificates of deposit), registered, stamped	6,000.00*	5,497.50*				5,497.50*
Total railroad bonds		$ 29,477.50			$4,253.78	$ 33,731.28
Public Utility Bonds:						
New York & Queens Electric Light & Power Company 3⅓% first and consolidated mortgage, due 1965	$10,000.00	$ 11,000.00				$ 11,000.00
United States Government Bonds:						
Treasury savings bonds series D, due July 1, 1949	10,000.00	$ 7,644.00				$ 7,644.00
Treasury savings bonds series D, due January 1, 1950	10,000.00	7,500.00				7,500.00
Treasury bonds 2%, due 1950/48	77,000.00	78,130.94				78,130.94
Treasury bonds 2%, due 1950/48, registered	3,000.00	3,060.94				3,060.94
Treasury bonds 2½%, due 1968/63	20,000.00	15,000.00	$5,000.00			20,000.00
Treasury bonds 2½%, due 1972/67	6,300.00	1,100.00		$5,200.00		6,300.00
Treasury bonds 2½%, due 1972/67, registered	3,500.00	3,516.41				3,516.41
Defense bonds series F, due June 1, 1953	34,000.00	25,160.00				25,160.00
Defense bonds series G 2½%, due December 1, 1954	18,000.00	18,000.00				18,000.00
Treasury savings bonds series G 2½%, due September 1, 1955	40,000.00	40,000.00				40,000.00
Treasury savings bonds series G 2½%, due November 1, 1956	17,000.00	17,000.00				17,000.00
Treasury savings bonds series G 2½%, due May 1, 1957	20,000.00	20,000.00				20,000.00
Treasury savings bonds series G 2½%, due October 1, 1957	30,000.00	30,000.00				30,000.00
Total United States Government bonds		$266,112.29	$5,000.00	$5,200.00		$276,312.29
Capital Stocks:						
American Can Company	40 shares	$ 4,988.40				$ 4,988.40
American Telephone & Telegraph Company	100 shares	17,454.15				17,454.15
Atchison, Topeka & Santa Fe Railway Company preferred	150 shares	13,035.46				13,035.46
Boston Edison Company	200 shares	4,927.50				4,927.50
Commonwealth Edison Company	200 shares	7,580.68				7,580.68
Consolidated Natural Gas Company	11 shares	221.92				221.92
Eastman Kodak Company	35 shares	4,768.23				4,768.23
E. I. du Pont de Nemours & Company	50 shares	7,982.07				7,982.07
General Electric Company	130 shares	4,463.80				4,463.80
General Motors Corporation $5 preferred	100 shares	12,785.00				12,785.00
General Motors Corporation	100 shares	4,235.53				4,235.53
International Harvester Company	100 shares	5,030.50				5,030.50
International Match Realization Company, Ltd. voting trust certificates for capital shares of International Match Corporation	6* shares	1,851.15*				1,851.15*
Louisville & Nashville Railroad Company	100 shares	6,278.13				6,278.13
Ohio Edison Company 4.40% preferred	150 shares	15,727.50				15,727.50
Pacific Gas and Electric Company	200 shares	8,784.35				8,784.35
Sears, Roebuck and Company	400† shares	6,014.97				6,014.97
Standard Oil Company of New Jersey	200 shares	9,601.26				9,601.26
Union Carbide & Carbon Corporation	100 shares	7,277.42				7,277.42
United Fruit Company	100 shares	11,985.00				11,985.00
United States Steel Corporation 7% cumulative preferred	100 shares	14,885.00				14,885.00
Total capital stocks		$169,878.02				$169,878.02
Total		$476,467.81	$5,000.00	$5,200.00	$4,253.78	$490,921.59
* Less reserve in full for securities considered to be of doubtful value		7,348.65				7,348.65
Total Securities, Less Reserve		$469,119.16	$5,000.00	$5,200.00	$4,253.78	$483,572.94

† Stock was split up in October 1945 by issuance of three additional shares for each one held.

HASKINS & SELLS
CERTIFIED PUBLIC ACCOUNTANTS

1 EAST 44TH STREET
NEW YORK 17

May 20, 1946

American Institute of Electrical Engineers,
33 West 39th Street, New York.

Dear Sirs:

We have examined the balance sheet of the American Institute of Electrical Engineers, and schedule of securities owned, as of April 30, 1946, and the related statements of cash receipts and disbursements of operating and restricted funds for the year ended that date, have reviewed the accounting procedures of the Institute, and have examined its accounting records and other evidence in support of such financial statements. Our examination was made in accordance with generally accepted auditing standards applicable in the circumstances and included all auditing procedures we considered necessary, which procedures were applied by tests to the extent we deemed appropriate in view of the system of internal control.

In our opinion, the accompanying balance sheet, schedule of securities owned, and statements of cash receipts and disbursements fairly present, respectively, the financial condition of, and securities owned by, the Institute as of April 30, 1946, and its recorded cash receipts and cash disbursements for the year ended that date, in conformity with generally accepted accounting principles and practices applied on a basis consistent with that of the preceding year.

Yours truly,

(*Signed*) HASKINS & SELLS

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

Balance Sheet, April 30, 1946

Exhibit A.

ASSETS			LIABILITIES		
Property Fund Assets:			**Property Fund Reserve**		$ 548,407.13
One-fourth interest in physical properties of United Engineering Trustees, Inc.:			**Restricted Fund Reserves:**		
Land, buildings, and equipment (less depreciation and renewal reserve)	$361,880.00		Reserve capital fund	$505,795.19	
Funded depreciation and renewal reserve	136,568.48		Life membership fund	8,684.75	
Total	$498,448.48		Member for life fund	5,031.09	
Equipment			International Electrical Congress of St. Louis library fund	5,878.05	
Library (volumes and fixtures)—estimated value	36,366.37		Lamme Medal fund	4,440.44	
Office furniture and fixtures (less reserve for depreciation, $27,761.27)	9,978.02		Mailloux fund	1,137.83	
Works of art, etc.	3,001.35		Total restricted fund reserves		530,967.35
Cash (no change during year)	612.91		**Operating Fund Reserves, Liabilities, etc.:**		
Total property fund assets		$ 548,407.13	Accounts payable	$ 15,455.58	
Restricted Fund Assets:			Deferred income:		
Securities—at cost, less reserve, $7,348.65 (quoted market value, $552,893.92)—Schedule 1	$483,572.94		Dues received in advance	4,503.14	
Cash (Exhibit C)	47,304.66		Entrance fees and dues advanced by applicants for membership	1,263.45	
Accrued interest receivable	89.75		Subscriptions to publications received in advance	17,940.01	
Total restricted fund assets		530,967.35	Miscellaneous (including unallocated receipts)	1,315.67	
Operating Fund Assets:			Operating fund reserves	84,620.36	
Cash (not including $1,302.87 for Federal taxes withheld from employees)—(Exhibit B)	$ 81,379.47		Total operating fund reserves, liabilities, etc.		125,098.21
Accounts receivable:					
Members—for dues (less reserve, $4,000.00)	8,133.58				
Advertisers	5,667.40				
Miscellaneous	3,649.99				
Accrued interest receivable	5,735.52				
Inventories:					
Transactions, etc.	1,054.00				
"Electrical Definitions"	3,668.40				
Work in process (May issue of *Electrical Engineering*, etc.)	6,140.28				
Text and cover paper	7,299.52				
Badges	2,370.05				
Total operating fund assets		125,098.21			
Total		$1,204,472.69	Total		$1,204,472.69

Exhibit B. Statement of Cash Receipts and Disbursements of Operating Fund for the Year Ended April 30, 1946

Cash on Deposit With The National City Bank of New York, May 1, 1945 (not including $1,295.18 for Federal taxes withheld from employees)		$ 77,206.09
Receipts:		
Dues (including $127,602.00 allocated to *Electrical Engineering* subscriptions)	$271,620.45	
Advertising	130,875.11	
Transactions subscriptions	8,557.39	
Electrical Engineering subscriptions	26,158.51	
"Electrical Definitions"	887.95	
"Electric Power Distribution for Industrial Plants"	2,769.00	
Miscellaneous publications (preprints, Standards, *Electrical Engineering* supplement, etc.)	23,468.40	
Students' fees	11,659.50	
Entrance fees	19,793.42	
Membership badges	4,468.61	
Transfer fees	3,601.29	
Interest and dividends on investments of Restricted Capital fund	13,389.09	
Barstow bequest (including interest of $652.03)	10,652.03	
Miscellaneous	541.44	
Total receipts		528,442.19
Total		$605,648.28
Disbursements:		
Publications expense:		
Electrical Engineering	$122,603.60	
Transactions	13,964.43	
Year Book	7,993.83	
Miscellaneous publications (preprints, Standards, "Industrial Plants" report, *Electrical Engineering* supplement, etc.)	19,771.44	
Institute meetings	15,310.00	
Institute Sections	44,899.10	
Institute Branches	2,872.01	
Finance committee	600.00	
Headquarters committee	83.87	
Membership committee	10,434.07	
Standards committee	15,681.37	
Forward	$254,213.72	$605,648.28

Total (forward)		$605,648.28
Disbursements (forward)	$254,213.72	
Technical committee	947.15	
Committee on institute publicity	840.33	
Planning and co-ordinating committee	3,122.18	
Joint committee—Economic Status of the Engineer	8.73	
Engineers Joint Council	870.13	
American Society of Civil Engineers handbook	250.00	
Retirement system AIEE—normal contribution	4,982.72	
Canadian Radio Technical Planning Board	318.17	
Radio Technical Planning Board	500.00	
Traveling expenses:		
Geographical Districts:		
Executive committees	5,240.17	
Vice-presidents	1,027.62	
Branch counselors and chairmen	1,280.61	
President's appropriation	1,840.79	
AIEE representatives	289.70	
Board of directors	7,171.50	
Nominating committee	1,253.85	
Administrative expenses	63,658.00	
Geographical Districts—Branch paper prizes	163.64	
Institute prizes—national	309.06	
American Co-ordinating Committee on Corrosion	25.00	
American Standards Association	1,750.00	
United Engineering Trustees, Inc.:		
Building assessment	17,813.64	
Library assessment	11,377.85	
Engineers' Council for Professional Development	1,852.00	
Engineering Foundation Project—Welding research	250.00	
National Committee State Board Engineering Examiners	500.00	
John Fritz Medal	50.00	
National Fire Protection Association—Dues	60.00	
Membership badges	5,265.20	
Legal services	250.00	
Lamme Medal expense (see Exhibit C)	191.03	
Office furniture and fixtures, and repairs	339.13	
Edison Medal committee	115.90	
Transfers:		
To reserve capital fund:		
Barstow bequest	10,652.03	
Other	123,726.58	
To Member for Life fund	1,762.38	
Total disbursements		524,268.81
Cash on Deposit With The National City Bank of New York, April 30, 1946 (not including $1,302.87 for Federal taxes withheld from employees)		$ 81,379.47

Exhibit C. Statement of Cash Receipts and Disbursements of Restricted Funds for the Year Ended April 30, 1946

		Restricted Funds					
	Total	Reserve Capital Fund	Member for Life Fund	*Life* Membership Fund	International Electrical Congress of St. Louis Library Fund	Lamme Medal Fund	Mallioux Fund
Cash on Deposit With The National City Bank of New York and Various Savings Banks, May 1, 1945	$ 35,064.88	$ 26,586.40	$3,268.71	$3,380.79	$531.80	$176.22	$1,120.96
Receipts:							
Income from bonds	$ 415.00			$ 125.00	$130.00	$160.00	
Interest on bank balances	65.26			48.39			$ 16.87
Transfers for operating fund:							
Barstow bequest	10,652.03	$ 10,652.03					
Other	125,488.96	123,726.58	$1,762.38				
Life membership fees	678.80			678.80			
Liquidating dividend—International Match Realization Company, Ltd.	24.00	24.00					
Total receipts	$137,324.05	$134,402.61	$1,762.38	$ 852.19	$130.00	$160.00	$ 16.87
Total	$172,388.93	$160,989.01	$5,031.09	$4,232.98	$661.80	$336.22	$1,137.83
Disbursements:							
Purchase of securities	$124,312.98	$124,312.98					
Transfer to operating fund	595.07			$ 595.07			
Purchase of medal, cost of engraving, etc. (exclusive of $191.03 paid from general fund)	176.22					$176.22	
Total disbursements	$125,084.27	$124,312.98		$ 595.07		$176.22	
Balance on Deposit With The National City Bank of New York and Various Savings Banks, April 30, 1946	$ 47,304.66	$ 36,676.03	$5,031.09	$3,637.91	$661.80	$160.00	$1,137.83

National and District Prize Awards for 1945 Announced

Recipients of the 1945 national prize awards for papers were announced by M. D. Hooven (F'44) chairman of the AIEE committee on award of Institute prizes at the annual meeting of the Institute, June 26, in Detroit, Mich. In the class of public relations and education the paper chosen was presented during the year 1944 when no award was made in that class. Owing to readjustments in the universities and colleges made necessary by the war, no papers were submitted for the national prize for Branch papers.

Each national prize award consists of an appropriately engrossed certificate and a check for $100 divided in the case of coauthors. The awards were as follows:

Best Paper in Engineering Practice. Prize awarded to James DeKiep (M'43) of the Electric Machinery Manufacturing Company, Minneapolis, Minn., and L. R. Hill and G. L. Moses (M'44) of the Westinghouse Electric Corporation, East Pittsburgh, Pa., for their paper, "The Application of Silicone Resins to Insulation for Electric Machinery," presented at the 1945 winter technical meeting, New York, N. Y., January 22–26, and published in the 1945 *Transactions*, pages 94–8. Honorable mention was awarded to L. J. Gorman (M'30) of the Consolidated Edison Company of New York, Inc., New York, N. Y., for his paper, "Electrolysis and Corrosion of Underground Power-System Cables," presented at the 1945 winter technical meeting, New York, N. Y., January 22–26, and published in the 1945 *Transactions*, pages 329–36.

Best Paper in Theory and Research. Prize awarded to G. D. McCann (M'44) and H. E. Criner of the Westinghouse Electric Corporation, East Pittsburgh, Pa., and C. E. Warren (A'41) of Ohio State University, Columbus, for their paper, "Determination of Transient Shaft Torques in Turbine Generators by Means of the Electrical–Mechanical Analogy," presented at the 1945 winter technical meeting, January 22–26, and published in the 1945 *Transactions*, pages 51–6. Honorable mention was awarded to V. E. Legg (M'37) of Bell Telephone Laboratories, Inc., New York, N. Y., for his paper, "Optimum Air Gap for Various Magnetic Materials in Cores of Coils Subject to Superposed Direct Current," published in the 1945 *Transactions*, pages 709–12.

Best Paper in Public Relations and Education. Prize awarded to Aram Boyajian (F'26) of the General Electric Company, Pittsfield, Mass., for his paper, "Cultural Training of the Engineer," presented at the 1944 winter technical meeting, January 24–28, and published in 1944 *Transactions*, pages 6–9.

Initial Paper. Prize awarded to G. W. Scott, Jr. (M'45) of the Armstrong Cork Company, Lancaster, Pa., for his paper, "The Role of Frequency in Industrial Dielectric Heating," published in the 1945 *Transactions*, pages 558–62. Honorable mention was awarded to H. M. Elsey (M'44) of the Westinghouse Electric Corporation, East Pittsburgh, Pa., for his paper, "Treatment of High-Altitude Brushes by Application of Metallic Halides," published in the 1945 *Transactions*, pages 576–9.

DISTRICT PRIZES

District prizes for AIEE papers have been announced by five Districts. The awards are for papers presented during 1945. Each District prize consists of an appropriately engrossed certificate and check for $25, divided in cases of coauthors.

District 2

Prize for best paper was awarded to E. W. Boehne (F'43) and W. A. Atwood for their paper, "Anode-Circuit-Breaker Design and Performance Criteria," presented at a meeting of the Philadelphia Section, February 12, 1945.

Prize for initial paper was awarded to William B. Keller (A'41) for his paper, "Aircraft Regulators and Relays," presented at a meeting of the Cleveland Section, December 4, 1945.

District 7

Prize for Branch paper was awarded to Duane G. Harman for his paper, "Hyper- and Ultrahigh-Frequency Effects on Vacuum Tubes," presented at a meeting held at Southern Methodist University, January 31 and February 1, 1945.

District 8

Prize for best paper was awarded to J. V. Kresser (M'43) for his paper, "Characteristics and Limitations of Transformer Connections," presented at a meeting of the San Francisco Section, November 16, 1945.

Prize for initial paper was awarded to C. J. Breitwieser (M'44) for his paper, "Constant-Speed Drives for Aircraft Alternators," published in the 1945 Transactions, pages 763–8.

District 9

Prize for best paper was awarded to E. C. Goodale (M'45) and J. I. Holbeck (M'36) for their paper, "Field Determination of Current Transformer Errors by the Secondary-Voltage Method," presented at a meeting of the Portland Section, April 3, 1945.

District 10

Prize for best paper was awarded to W. B. Buchanan (M'32) and G. D. Floyd (M'28) for their paper, "Field Tests of Interrupting Capacity of 138-Kv Oil Circuit Breakers," presented at a meeting of the Toronto Section, October 12, 1945.

Trial Period Extended on Members-for-Life Awards

A four-year instead of a two-year trial period for the awards of trips to the summer convention to winners of the District prizes for Branch papers has been decided upon. The decision of the committee on members-for-life fund was made in view of the disturbed conditions which have prevailed in the universities and colleges during the past few years.

The awards which were announced in the January 1945 issue of *Electrical Engineering*, page 31, provide for the payment of expenses of five winners of District prizes for Branch papers to the summer convention for the purpose of presenting their papers. The even-numbered Districts would be eligible one year, and the odd-numbered ones the next. Experience gained in the next four years will determine whether or not the utilization of the members-for-life fund for this purpose will be continued permanently.

Board of Directors Meeting Held in Asheville

The regular meeting of the AIEE board of directors was held at Grove Park Inn, Asheville, N. C., May 14–15, 1946, during the Southern District meeting of the Institute.

The board confirmed its previous action by letter ballot authorizing a contribution of $15,000 toward a survey by the United Engineering Trustees, Inc., of the situation with respect to the increasing inadequacy of the engineering societies headquarters building for the Founder Societies and the need for its renovation or for a new building. The AIEE board has gone on record as recommending that UET explore the possibility of creating or obtaining adequate headquarters for all national engineering societies and kindred organizations which may wish to participate.

The Institute's annual appropriation for the American Co-ordinating Committee on Corrosion was increased from $25 to $50, and the annual payment to the United States National Committee of the International Commission on Illumination was increased to $150.

Sections committee recommendations for an increase in the financial allotments to those Sections having definitely increased activities, for which the present appropriations are inadequate, were confirmed as the basis for Sections' appropriations during the coming year. These recommendations were for the retention of the basic yearly allotments of $200 to each Section and $1.20 for each Institute member within the Section on August 1, and for an increase in the allotments for additional regularly scheduled meetings of the Section, Subsections, and technical groups in the Section during the preceding fiscal year as indicated below:

Number of Meetings	Proposed Allotment	Present Allotment
12 to 17	$ 50	$25
18 to 23	100	50
24 to 29	150	75
30 or more	200	75

Also recommended was a basic yearly allotment of $100 to a Section for the operation of each Subsection holding regularly scheduled meetings.

An extensive discussion of Institute activities resulted in actions concerning technical committees, Institute publications, and headquarters staff functions reported in the June issue (pages 269–70). The subject of visits of the president with Sections was given comprehensive consideration, as the Institute has grown so large that changes in the policy regarding such visits are essential. The committee on planning and co-ordination was requested to study the subject and make recommendations. By vote, the board strongly commended the committee on planning and co-ordination and its subcommittees on technical activities and professional activities, and emphatically recommended continuance of their work next year.

Upon request of the District officers, payment in September of the present appropriation year of travel expenses in connection with the North West District executive committee meeting for 1946–47, which is to be held during the Pacific Coast convention in August (in advance of the 1946–47 appropriation year), was authorized.

A meeting of the North Eastern District was authorized to be held in Worcester, Mass., April 23–25, 1947.

The chairman of the 1946 winter convention committee, who has been making some tentative arrangements for the 1947 convention, having requested a definite statement of the board's policy regarding exhibits of electric equipment which might be held concurrently with the convention,

the board voted to authorize the use by an exhibit company of the phrase "to be held concurrently with the AIEE winter convention."

The board referred to the technical program committee an inquiry as to whether the Institute could supply some technical papers for the National Electronics Conference, to be held in Chicago, Ill., October 3–5, 1946, and approved a proposal of that committee that the chairman of the committee on electronics appoint a subcommittee of three AIEE members in the Chicago Section to arrange for AIEE participation in the conference.

Upon recommendation of the Standards committee, the board took the following actions: Approved the appointment of R. C. Putnam (M '34) as AIEE representative, and Professor E. M. Strong (M '40) as alternate, on ASA Sectional Committee A23, which will undertake a revision of the "American Recommended Practice for School Lighting" (in place of former representative G. H. Stickney (F '24) who has retired); approved the appointment of Professors C. L. Dawes (F '35) and D. T. Canfield (M '31) as AIEE representatives on Sectional Committee C12, which will undertake a revision of the "Code for Electricity Meters" (to replace the two former representatives, who have resigned).

As the result of the board's approval in October 1945 of a recommendation that the definition of a "university or technical school of recognized standing" be made consistent with the present practice of accrediting engineering schools by The Engineers Council for Professional Development, section 51 of the bylaws was amended to read as follows:

Sec. 51. Any person registered as a student, graduate, or undergraduate, in a university or technical school of recognized standing may be enrolled as a Student member of the American Institute of Electrical Engineers, except that a graduate student whose term of enrollment, as specified in Section 53, has expired may not again enroll. The expression "university or technical school of recognized standing" is interpreted as applying to any school of college grade which provides an engineering curriculum which prepares students for the profession of electrical engineering and which is fully accredited by Engineers' Council for Professional Development. If the curriculum is not fully accredited by Engineers' Council for Professional Development, the Board may waive this requirement on the recommendation of the committee on Student Branches.

In accordance with section 37 of the constitution, the appointment of a secretary of the Institute for the administrative year commencing August 1, 1946, was considered, and Secretary H. H. Henline was reappointed with an expression of appreciation of his efficient services.

Vice-President M. S. Coover (F '42) was appointed a representative of the Institute on the Washington Award Commission for the two-year term commencing June 1, 1946, succeeding L. R. Mapes (F '37) whose term expired at that time.

Upon recommendation of the executive committees of the Districts concerned and the chairman of the Sections committee and upon request of the San Francisco Section, the Territory of Hawaii was transferred from the New York City District (3) to the Pacific District (8), and added to the territory of the San Francisco Section.

Report was made of the continued cooperation of the committee on air transportation with the Society of Automotive Engineers and the National Aircraft Standards Committee in aeronautical electrical standardization work.

Appointment by the president of the following committee of tellers, to canvass, count, and report on the ballots for the election of AIEE officers, was approved:

Charles H. Wagner (F '40) *chairman;* D. F. Hall (A '43); E. W. Hilbert (M '46); K. K. Lacher (A '45); R. R. MacGregor (A '42); Charles S. Murray, Jr. (A '34); and Earl G. Ports (M '34).

General funds disbursements for April, a total of $40,205.53, were reported by Chairman W. R. Smith of the finance committee and approved.

A resolution was adopted directing the removal from the active membership list of the names of the members in arrears for dues of the fiscal year which commenced May 1, 1945, and extending the time for the payment of such dues until further action by the board of directors.

Present at the meeting were:

President—W. E. Wickenden, Cleveland, Ohio. *Past President*—C. A. Powel, East Pittsburgh, Pa. *Vice-Presidents*—C. B. Carpenter, Portland, Oreg.; F. F. Evenson, San Diego, Calif.; J. F. Fairman, New York, N. Y.; E. S. Fields, Cincinnati, Ohio; R. T. Henry, Buffalo, N. Y.; F. L. Lawton, Montreal, Canada; Herman B. Wolf, Charlotte, N. C. *Directors*—P. L. Alger, Schenectady, N. Y.; J. M. Flanigen, Atlanta, Ga.; C. W. Mier, Dallas, Tex.; S. H. Mortensen, Milwaukee, Wis.; W. B. Morton, Allentown, Pa.; J. R. North, Jackson, Mich.; D. A. Quarles, New York, N. Y.; Walter C. Smith, San Francisco, Calif.; W. R. Smith, Newark, N. J. *Secretary*—H. H. Henline, New York, N. Y. By invitation: J. Elmer Housley, *presidential nominee;* E. W. O'Brien, *chairman,* committee on Student Branches; M. D. Hooven, *chairman,* technical activities subcommittee of the committee on planning and co-ordination.

Annual Additions to List of Members for Life

Membership for life is granted by the AIEE to members who either have paid annual dues for 35 years, or have reached the age of 70 and paid dues for 30 years. A list of those who have become members for life during the preceding year is published annually in *Electrical Engineering.* Institute members who have attained this status since publication of the last list in the July 1945 issue are:

R. V. Achatz
A. J. Althouse
G. M. Armbrust
J. R. Arthur
A. Bachrach
S. A. K. Barrett
W. R. Battey
A. E. Bauhan
H. Baum
W. E. Beaty
R. Beman
C. E. Bennett
N. C. Benson
E. L. Bettanier
B. K. Boyce
F. F. Brand
H. P. Broderson
R. A. Brown
R. P. Brown
H. H. Buell
W. H. R. Burrows
H. A. Burt
E. R. Candor
R. F. Carbutt
W. N. Chaffee
P. I. Chandeysson
C. E. Connard
H. A. Cowgill
J. S. Cruikshank
A. C. Cummins
R. E. Cunningham
L. M. Dawes
E. E. de Souza
F. E. d'Humy
G. H. Dorgeloh
H. G. Dorsey
C. W. Drake
J. V. B. Duer
C. H. Eames
R. N. Early
C. T. Evans
F. R. Ewart
W. S. Ewens
D. D. Ewing
R. H. Fenkhausen
G. Fiske
C. E. Fleager
S. G. Forbes
B. P. Foster
R. A. Fulton
P. M. Fee
L. S. Goodman
M. C. Goodspeed
H. Goodwin, Jr.
H. P. Gorman
S. B. Graham
A. H. Grimsley
F. M. Gunby
C. I. Hall
M. S. Hall
H. B. Hammond
R. H. Harvey
L. F. Harza
G. C. Hecker
H. H. Henningson
G. Hirsch
L. W. Hitchcock
J. V. L. Hogan
R. B. Howland
A. P. Hyatt
G. C. Hyde
A. W. Janowitz
C. A. Jaqua
F. Jeffrey
C. G. Johnson
B. W. Jones
J. A. Jones
R. L. Jones
L. G. Josepha, Jr.
G. A. Kehall
W. P. Kennedy
L. M. Klauber
G. L. Knight
J. A. Koontz, Jr.
G. E. Lewis
F. M. Loud
O. MacMurray
F. W. MacNeill
E. H. Martindale
A. L. Matte
E. L. Moreland
J. J. Mullen
J. F. Murray
E. R. Nigh
A. A. Nims
H. B. Noack
R. Norse
E. L. Nute
H. S. Osborne
R. Page
G. K. Paton
L. T. Peck
G. G. Post
O. G. Pratt
R. L. Quass
K. Richards
H. K. Ritter
C. A. Robinson
M. H. Roffey
G. H. Schaeffer
H. J. Schiefer, Jr.
E. G. Schmeiser
A. P. C. Schramm
G. Smith
J. U. Smith
G. T. Southgate
G. E. Stack
R. T. Stafford
E. H. Steele
A. B. Stewart
E. N. Strait
L. V. Sutton
F. Swanstrom
C. F. Terrell
L. A. Terven
P. Thomas
A. C. Towers
J. O. Tucker
J. S. van Bylevelt
S. G. Vinson
C. P. Walker
C. A. M. Weber
A. F. Welch
F. M. Weller
R. B. Wendell
R. L. Witham

Section and Branch Activities—Annual Report for 1945–46

The following constitutes the annual report on Institute Section and Branch activities for the fiscal year which ended April 30, 1946. Similar information for three preceding fiscal years appeared in *Electrical Engineering* in June 1945, pages 228–9; June 1944, pages 224–5; and June 1943, pages 264–5.

Present members of the Sections committee and the committee on Student Branches, supervising the divisions of Institute activities covered by this report, which appears on the following pages are:

Sections—G. W. Bower, *chairman;* R. M. Pfalzgraff, *vice-chairman;* A. C. Muir, *secretary;* O. C. Brill; M. S. Coover; W. E. Enns; C. W. Evans; F. F. Evenson; H. P. Healer; V. P. Hessler; W. R. Hough; Frederick Krug; F. L. Lawton; T. M. Linville; E. T. Mahood; R. G. Porter; C. S. Purnell; and, ex officio, chairmen of all Institute Sections.

Branches—E. W. O'Brien, *chairman;* M. M. Cory; H. L. Davis, Jr.; A. G. Ennis; T. G. LeClair; Everett S. Lee; Walter Charles Smith; R. M. Strong; R. G. Warner; C. R. Wischmeyer; and, ex officio, all Student Branch counselors.

Table I. Section Membership and Meetings During Year Ending April 30, 1946

Section	AIEE Members August 1946	AIEE Members August 1945	Number of Meetings	Average Attendance
Akron	104	105	8	69
Electronic technical discussion group			2	70
Alabama	44	37	8	41
Arizona	50	60	9	47
Beaumont		61	11	59
Boston	604	673	10	261
Electronics group			3	150
Industrial power application group			3	87
Instruments and measurements group			4	90
Insulation group			2	82
Transmission and distribution group			4	74
Central Indiana	148	147	10	79
Chicago	869	961	3	172
Communications group			4	145
Electronics group			4	179
Industrial group			4	72
Power group			4	118
Cincinnati	149	161	11	256
Electronics discussion group			4	50
General industrial applications discussion group			2	51
Technical discussion group			2	56
Cleveland	390	424	16	280
Electronics group			8	29
Illumination group			1	6
Motors and control technical group			2	53
Columbus	84	90	8	93
Zanesville Subsection			12	22
Connecticut	363	384	6	84
Dayton	173	243	10	151
Aeronautical technical discussion group			6	51
Industrial electronics technical discussion group			5	31
Motors and control technical discussion group			5	60
Denver	192	209	9	88
East Tennessee	206	288	17	83
Technical group meetings			9	17
Erie	74	73	10	52
Florida	134	125	2	55
Florida West Coast Subsection			1	30
Miami Subsection			1	39
Fort Wayne	107	107	10	41
Georgia	115	145	12	97
Houston	180	143	11	67
Communications technical group			4	28
Industrial applications technical group			4	30
Illinois Valley		47	15	92
Electronics – radio technical group			4	40
Industrial maintenance technical group			1	105
Power distribution technical group			2	18
Production and transmission technical group			1	8
Iowa	78	85	4	24
Ithaca	65	72	10	105
Dielectric heating discussion group			6	33
Kansas City	146	149	13	110
Electronics group			4	9
Industrial practice technical group			16	8
Lehigh Valley	179	188	9	67
Los Angeles	635	723	9	208
Boulder Dam Subsection			3	30
Aircraft division			7	77
Electronics division			5	153
Power division			3	197
Louisville	75	75	8	54
Lynn	211	210		
Madison	75	81	7	35
Rock River Valley Subsection			8	62
Mansfield	65	63	8	121
Maryland	381	417	10	185
Lancaster – York Subsection			7	100
Memphis	72	94	10	36
Little Rock Subsection			6	34
Mexico	83	181		
Michigan	404	435	7	155
Saginaw Valley Subsection			6	99
Electronics group			4	64
Industrial power group			1	269
Round table meetings			5	81
Milwaukee	371	409	11	254
Basic sciences group			4	50
Electric machinery group			4	36
Electronics group			6	50
Power applications and control group			4	60
Transmission and distribution group			3	32
Minnesota	124	133	11	98
Arrowhead Subsection			8	71
Montana	36	71	7	36
Great Falls Subsection			8	27
Montreal	208	237	14	130
Ottawa Subsection			11	47
Muscle Shoals	22	19	8	23
Nebraska	51	48	6	38
New Mexico – West Texas	54	57	13	47
Albuquerque Subsection			5	17
Technical group meetings			6	15
New Orleans	151	159	10	74
Lake Charles Subsection			9	27
Shreveport Subsection			2	26
New York	3,814	3,949	2	340
Basic science group			6	148
Communication group			6	488
Illumination group			4	277
Power and industrial group			9	126
Transportation group			3	37
New Jersey activities committee			4	184
Niagara Frontier	185	198	8	74
Niagara Falls Subsection			4	58
North Carolina	119	137	1	
Charlotte Subsection			5	27
North Texas	177	199	10	81
Panhandle Subsection			9	39
Oklahoma City	100	109	9	98
A-c circuit analysis group			5	7
Electronics group			5	12
Frequency modulation group			4	6
Joint rural service group			4	9
Physics and nuclear physics group			3	4
Transmission and distribution group			4	12
Philadelphia	892	925	10	195
Wilmington Subsection			10	95
Electrification of industrial plants discussion group			3	15
Aircraft electrical engineering discussion group			1	30
Basic science discussion group			2	153
Communication discussion group			4	198
Electronics discussion group			3	37
Industrial practice discussion group			3	43
Instruments and measurements discussion group			3	90
Power systems discussion group			3	46
Pittsburgh	663	693	12	177
Pittsfield	196	200	8	109
Popular lectures			6	1,100
Electronics technical group			5	23
Portland	189	228	16	117
Communications group			1	130
Electrochemical and electrometallurgical group			1	38
Industrial electronic group			4	112
Marine technical group			1	34
Transmission and distribution group			1	100
Providence	101	105	8	167
Rochester	124	133	8	171
Luncheon meetings			4	43
Communications group			1	108
Power discussion group			1	30
St. Louis	320	347	11	111
Electronics discussion group			5	14
Industrial power practices discussion group			5	17
San Diego	74	102	12	66
San Francisco	682	771	13	221
Fresno Subsection			5	74
Sacramento Subsection			8	75
Electronics group			7	58
Industrial practices group			5	47
Power group			4	54
Schenectady	619	654	5	396
Technical discussion meetings			4	185
Aviation group			6	85
Industrial electronics group			4	59
Industrial power applications group			4	38
Seattle	274	304	13	149
Aircraft technical group			1	138
Electronics technical group			3	95

Table I. Section Membership and Meetings During Year Ending April 30, 1946 (Continued)

Sections	AIEE Members August 1944	AIEE Members August 1945	Number of Meetings	Average Attendance
Power technical group			4	53
Sharon	135	149	9	106
South Bend	60	70	10	46
Industrial power problems technical group			2	13
South Carolina	47	56	2	68
Charleston Subsection			2	15
South Texas	48	56	7	46
Spokane	103	106	9	45
Springfield	55	60	9	107
Electronics group			6	23
Syracuse	126	149	7	125
Toledo	87	67	10	52
Toronto	381	400	16	206
Hamilton Subsection			8	78
Niagara District Subsection			1	50
Communications technical group			3	54
Discussion group			9	42
Tulsa	73	81	8	67
Technical meetings			9	8
Urbana	87	38	4	50
Utah	79	77	15	59
Vancouver	101	109	11	120
Virginia	147	138	4	174
Hampton Roads Subsection			4	55
Richmond Subsection			2	34
Washington	707	724	10	294
Technical group meetings			8	94
West Virginia	39	50	10	133
Wichita	74	86	12	68
Worcester	65	59	8	65
	18,415	19,918	1,187	

Total Sections, 75 — Total technical groups, 85
Total Subsections, 25 — Total Attendance, 116,294

Table II. Section Meetings Held During Last Three Fiscal Years

	Fiscal Year Ending April 30		
	1944	1945	1946
Number of Sections	73	73	75
Number of meetings held	738	884	1,187
Average number of meetings	10.1	12.1	15.8
Total attendance	83,120	96,346	116,294
Average attendance per meeting	113	109	98

Table III. Branch Meetings Held During Last Three Fiscal Years

	Fiscal Year Ending April 30		
	1944	1945	1946
Number of Branches	125	125	125
Number of meetings held	755	542	718
Average number of meetings	6.0	4.3	5.8
Total attendance	24,768	17,137	23,473
Average attendance per meeting	33	32	33

Table IV. Branch Meetings Held During Year Ending April 30, 1946

Branch	Number	Average Attendance
Akron, University of	4	33
Alabama Polytechnic Institute	0	0
Alabama, University of	0	0
Alberta, University of	6	29
Arizona, University of	0	0
Arkansas, University of	6	12
British Columbia, University of	18	35
Brooklyn, Polytechnic Institute of		
Day division	8	44
Evening division	2	19
Brown University	2	39
Bucknell University	1	23
California Institute of Technology	8	38
California, University of	8	34
Carnegie Institute of Technology	51	28
Case School of Applied Science	7	54
Catholic University of America	3	10
Cincinnati, University of	0	0
Clarkson College of Technology	2	15
Clemson Agricultural College	10	17
Colorado State College	0	0
Colorado, University of	13	77
Columbia University	13	32
Connecticut, University of	0	0
Cooper Union		
Day division	3	15
Evening division	0	0
Cornell University	11	59
Delaware, University of	1	15
Denver, University of	5	25
Detroit, University of	6	30
Drexel Institute of Technology	5	37
Duke University	16	40
Florida, University of	1	55
George Washington University	5	44
Georgia School of Technology	0	0
Harvard University	1	26
Idaho, University of	8	24
Illinois Institute of Technology	10	52
Illinois, University of	3	29
Iowa State College	2	9
Iowa, University of	12	14
Johns Hopkins University	8	14
Kansas State College	10	68
Kansas, University of	2	30
Kentucky, University of	11	36
Lafayette College	2	15
Lehigh University	1	28
Louisiana State University	8	17
Louisville, University of	8	49
Maine, University of	0	0
Manhattan College	5	30
Marquette University	9	27
Maryland, University of	5	23
Massachusetts Institute of Technology	6	136
Michigan College of Mining and Technology	8	0
Michigan State College	1	20
Michigan, University of	12	57
Milwaukee School of Engineering	2	187
Minnesota, University of	0	0
Mississippi State College	6	16
Missouri School of Mines and Metallurgy	0	0
Missouri, University of	6	21
Montana State College	8	18
Nebraska, University of	9	18
Nevada, University of	0	0
Newark College of Engineering	2	23
New Hampshire, University of	0	0
New Mexico State College	3	12
New Mexico, University of	1	39
New York, College of the City of		
Day division	18	47
Evening division	0	0
New York University		
Day division	0	0
Evening division	7	40
North Carolina State College	5	28
North Dakota Agricultural College	2	10
North Dakota, University of	0	0
Northeastern University	8	31
Northwestern University	7	40
Norwich University	0	0
Notre Dame, University of	3	36
Ohio Northern University	1	9
Ohio State University	6	11
Ohio University	0	0
Oklahoma Agricultural and Mechanical College	2	34
Oklahoma, University of	6	40
Oregon State College	8	33
Pennsylvania State College	3	43
Pennsylvania, University of	3	41
Pittsburgh, University of	15	96
Pratt Institute	0	0
Puerto Rico, University of	5	28
Princeton University	4	14
Purdue University	11	0
Rensselaer Polytechnic Institute	2	14
Rhode Island State College	0	0
Rice Institute	9	31
Rose Polytechnic Institute	2	16
Rutgers University	1	15
Santa Clara, University of	0	0
South Carolina, University of	5	24
South Dakota State College	7	34
South Dakota State School of Mines	4	14
Southern California, University of	18	22
Southern Methodist University	0	0
Stanford University	2	35
Stevens Institute of Technology	0	0
Swarthmore College	0	0
Syracuse University	1	5
Tennessee, University of	7	19
Texas Agricultural and Mechanical College	6	32
Texas Technological College	10	20
Texas, University of	12	55
Tufts College	4	33
Tulane University	10	27
Union College	7	33
Utah, University of	5	28
Vanderbilt University	4	12
Vermont, University of	1	46
Villanova College	10	33
Virginia Military Institute	1	25
Virginia Polytechnic Institute	12	51
Virginia, University of	19	33
Washington, State College of	11	32
Washington, University of	6	79
Washington University	8	21
West Virginia University	7	9
Wisconsin, University of	11	26
Worcester Polytechnic Institute	2	25
Wyoming, University of	11	19
Yale University	5	57
	718	

Total, 125 Branches

Joint Inspection Trip Ends Season for Pittsburgh Section

A joint meeting with the electrical section of the Engineers' Society of Western Pennsylvania held at the Springdale station of the West Penn Power Company, May 14, drew an attendance of more than 250 to the last technical meeting of the 1945–46 season of the Pittsburgh Section.

Inspection of the company's number 7 addition was the chief attraction of the trip to the station 20 miles from Pittsburgh. Representatives of many suppliers of major equipment installed in the station also were present.

The group was welcomed by E. F. Randolph, superintendent of the Springdale station. Electrical features of the new addition were discussed by H. A. P. Langstaff (F '43) electrical engineer of the company, and mechanical details were explained by J. T. Rummell.

Communications and Electronics Group Formed in Georgia

An address on "Recent Developments in Electronics" by Doctor R. I. Sarbacher (M '41) dean of the graduate studies division, Georgia School of Technology, Atlanta, was featured at the first meeting of the technical group on communications and electronics of the AIEE Georgia Section. Approximately 75 members and guests attended the evening meeting.

Officers of the newly organized technical group, which has 39 charter members, are:

Chairman—R. I. Sarbacher.

Vice-chairman—Newton B. Fowler, division plant supervisor, American Telephone and Telegraph Company, Atlanta.

Secretary-treasurer—Robert P. Posey, consulting application engineer, Westinghouse Electric Corporation, Atlanta.

Prize Paper Meeting Held at Sharon

The May meeting of the Sharon Section was devoted to the presentation of four prize papers and two which had received honorable mention in a contest which originated last fall. A prize paper committee was set up at that time to encourage the submission of technical papers, and the May meeting was the culmination of its program.

A total of 11 papers was received and passed on by a board of three judges. Two presentation prizes also were awarded, and all six winners were equally eligible for these. The four paper prizes were $37.50, $25, $15, and $7.50. The presentation prizes were $10 and $5.

The meeting was one of the best attended of the year and the program is being considered as an annual event.

PERSONAL ....

James DeKiep (M '43) chief engineer, Electric Machinery Manufacturing Company, Minneapolis, Minn., has been awarded the 1945 national best paper prize in the field of engineering practice as coauthor of the paper, "The Application of Silicone Resins to Insulation for Electric Machinery." Born in Grand Haven, Mich., in 1905, Mr. DeKiep was graduated from the University of Michigan in 1927 with the degree of bachelor of science in electrical engineering. He joined the Westinghouse Electric Corporation, East Pittsburgh, Pa., in 1929, working on the design and application of a-c motors and generators until 1942, at which time he was made section engineer in charge of the a-c section of the motor engineering department. He entered the employ of the Electric Machinery company in 1945.

G. L. Moses (A '43, M '44) section engineer, development insulation, transportation and generator division, Westinghouse Electric Corporation, East Pittsburgh, Pa., has been awarded the 1945 national best paper prize in the field of engineering practice as coauthor of the paper, "The Application of Silicone Resins to Insulation for Electric Machinery." Mr. Moses was born in Knoxville, Tenn., in 1904, and attended Bliss Electrical School. He entered the employ of the Westinghouse company as a member of the student training course in 1923. He has been sales correspondent, railway control engineer, and coil and insulation engineer. Since 1942 he has been engineer in charge of the insulation development group.

C. E. Warren (A '41) assistant professor of electrical engineering, Ohio State University, Columbus, has received the 1945 national best paper prize in the field of theory and research as coauthor of the paper, "Determination of Transient Shaft Torques in Turbine Generators by Means of the Electrical–Mechanical Analogy." Professor Warren was born in 1914 in Columbus, Ohio, and received the degree of bachelor of electrical engineering from Ohio State University in 1938 and the degree of master of science from Massachusetts Institute of Technology in 1940. He was assistant in electrical engineering at Massachusetts Institute of Technology, Cambridge, from 1938 to 1940 and in 1940 entered the employ of the Westinghouse Electric Corporation, East Pittsburgh, Pa., as industry engineer. He joined the staff of Ohio State University in 1944.

G. D. McCann (A '38, M '44) consulting transmission engineer, industry engineering department, Westinghouse Electric Corporation, East Pittsburgh, Pa., has been awarded the national best paper prize for 1945 in the field of theory and research as coauthor of the paper, "Determination of Transient Shaft Torques in Turbine Generators by Means of the Electrical–Mechanical Analogy." Doctor McCann was born in Glendale, Calif., in 1912, and holds the degrees of bachelor of science (1934) master of science (1935), and doctor of philosophy (1939) from California Institute of Technology. He was teaching fellow at the California Institute of Technology, Pasadena, from 1935 to 1938 and in 1938 joined the Westinghouse corporation as transmission engineer. He is the author of numerous papers and a member of Sigma Xi.

Aram Boyajian (A '18, F '26) electrical engineer, General Electric Company, Pittsfield, Mass., has been awarded the national best paper prize for 1945 in the field of public relations and education for his paper, "Cultural Training of the Engineer." Mr. Boyajian was born in Armenia in 1888, and received the bachelor of arts degree from Anatolia College, and his bachlor of science degree in 1915 and his electrical engineering degree in 1918 from Swarthmore College. He has been engaged in consulting engineering for the General Electric Company since 1917. He has published a number of papers and articles.

G. W. Scott, Jr. (M '45) assistant chief physicist, Armstrong Cork Company, Lancaster, Pa., has been awarded the 1945

James De Kiep

C. E. Warren

G. L. Moses

national prize for initial paper for his paper, "The Role of Frequency in Industrial Dielectric Heating." Doctor Scott, who was born in 1912 in Auburn, N. Y., received the degree of bachelor of arts from Wesleyan University in 1934 and the degrees of master of arts in 1935 and doctor of philosophy in 1938 from Cornell University. From 1938 to 1940 he had a post doctorate fellowship in applied electronics at Massachusetts Institute of Technology, Cambridge. In 1940 he became a research associate at the institute. He joined the Armstrong company in 1941. He was a teaching and research assistant at Cornell University, Ithaca, N. Y., from 1934 to 1938. Doctor Scott has published a number of papers and is a member of the American Physical Society, the American Welding Society, and Sigma Xi.

Aram Boyajian

G. D. McCann

G. W. Scott, Jr.

L. J. Gorman (A '11, M '30) assistant engineer, electrical engineering department, Consolidated Edison Company of New York (N. Y.), Inc., has received honorable mention in the field of engineering practice in the 1945 national prize paper awards for his paper, "Electrolysis and Corrosion of Underground Power System Cables." Born in Waddington, N. Y., in 1887, Mr. Gorman received his bachelor of science degree from Clarkson College of Technology in 1909. After graduation he spent one year each with the General Electric Company, Schenectady, N. Y., and one with Stevens Institute of Technology, Hoboken, N. J. In 1911 he entered the employ of New York Edison Company and, except during World War I when he served overseas as a captain in the Signal Corps, has been with the Edison system ever since. He has been tester, foreman, general foreman, electrolysis engineer, and assistant engineer.

V. E. Legg (M '37) engineer in the apparatus development department, Bell Telephone Laboratories, Inc., New York, N. Y., has received honorable mention in the field of theory and research for his paper, "Optimum Air Gap for Various Magnetic Materials in Cores of Coils Subject to Superposed Direct Current," in the 1945 national prize paper awards. Born in Ann Arbor, Mich., in 1897, Mr. Legg holds the degrees of bachelor of science (1920) and master of science (1922) from the University of Michigan. He was research physicist with the Detroit Edison Company in 1920 and 1921 and in 1923 entered the research department of the Western Electric Company, which in 1925 became the Bell Telephone Laboratories. He since has been engaged in cable research and has more than 20 patents, both American and British, to his credit. From 1929 to 1931 he was in Germany supervising the manufacture and application of continuous loading to experimental telephone cable. He is a member of the American Society for Metals, the American Physical Society, and the American Association for the Advancement of Science.

H. M. Elsey (M '44) consulting chemist, Westinghouse Research Laboratories, Westinghouse Electric Corporation, East Pittsburgh, Pa., has received honorable mention for initial paper in the 1945 national prize paper awards for his paper, "Treatment of High-Altitude Brushes by Application of Metallic Halides." Born in 1891 in Seattle, Wash., Mr. Elsey received the degrees of bachelor of arts in 1914, master of arts in 1915, and doctor of philosophy in 1919 from Stanford University. He joined the faculty of the University of Kansas, however, in 1918 as assistant professor of chemistry and was appointed associate professor in 1921. Since 1925 he has been consulting chemist for the Westinghouse corporation. He is a member of the American Chemical Society, the American Association for the Advancement of Science, the Chemical Society (London, England), and the Society of Chemical Industry.

Ralph Bown (M '30, F '41) formerly assistant director of research, Bell Telephone Laboratories, Inc., New York, N. Y., has been named director of research. He succeeds **M. J. Kelly** (M '26, F '31) who has been serving as both director of research and executive vice-president and who will continue in the latter position. Doctor Bown received the degree of mechanical engineer from Cornell University in 1913, the master's degree in 1915 and his doctor's degree in 1917. During World War I he was officer in charge of radio development work at the United States Army Signal Corps Radio Laboratories at Camp Alfred Vail, N. J. Afterwards he joined the department of development and research of the American Telephone and Telegraph Company. In 1934 he was appointed associate director of radio research for the laboratories, and in 1937 director of radio and television research. He became assistant director of research in 1944. He served as division member and consultant to the National Defense Research Council and was sent to England to study radar in 1941. He also was a War Department consultant. Doctor Bown was president of the Institute of Radio Engineers in 1927 and in that year received the Morris Liebmann prize in recognition of his research into wave transmission phenomena.

H. P. Sleeper (A '22, M '30) operating engineer, electric distribution department, Public Service Electric and Gas Company, Newark, N. J., has been presented with the company's Thomas N. McCarter Electric Award for 1945 "in recognition of his leadership and direction in the development of relay protection for the transmission and distribution system which has resulted in notably improved service reliability and substantial savings in system investment." The award is given annually to the employee in either the operating or commercial group of the electric department who contributed most during the year toward the efficiency and progress of the department. Mr. Sleeper, a graduate of the University of Maine, joined the Public Service Company in 1925 and has been operating engineer since 1940. He has been chairman of the AIEE committee on protective devices. Mr. Sleeper, a veteran of World War I, has been active in the moral rearmament movement and in 1945 participated in the training center activities at Mackinac Island, Mich., which were attended by leaders in government and industry from the United States, Canada, and other countries.

T. G. LeClair (A '24, F '40) chief staff engineer, Commonwealth Edison Company, Chicago, Ill., has been elected president of the Western Society of Engineers for the year 1946–47. With the Edison company since 1923, Mr. LeClair has held the positions of cable engineer, assistant field engineer, engineer of system protection, development engineer, and staff engineer. Mr. LeClair, at present an AIEE vice-president, has served on many AIEE committees. He is currently chairman of the professional activities subcommittee of the committee on planning and co-ordination. He is a director and past president of the Illinois Engineering Council and a member of the Illinois Society of Engineers and the National Society of Professional Engineers. A fuller biography of Mr. LeClair may be found in the March 1946 issue of *Electrical Engineering*, page 132.

Walther Richter (M '37, F '42) electrical engineer, engineering development department, Allis-Chalmers Manufacturing Company, West Allis, Wis., has been elected chairman of the AIEE Milwaukee Section for the 1946–47 season.

F. J. Van Zeeland (A '37, M '44) dean and professor of electrical engineering, Milwaukee (Wis.) Engineering School, has been elected secretary–treasurer of the AIEE Milwaukee Section for 1946–47.

W. G. H. Finch (A '22, M '26) president, Finch Telecommunications, Inc., Passaic, N. J., and captain in the United States Naval Reserve, recently was awarded the Legion of Merit "for exceptionally meritorious conduct in the performance of outstanding service to the Government of the United States as head of the Countermeasures Design Section, Electronics Division, Bureau of Ships, from December 1, 1941 to September 1, 1945."

N. L. Freeman (M '45) design engineer, American Locomotive Company, Schenectady, N. Y., has been appointed a member of the New York State Board of Examiners for Professional Engineers and Land Surveyors. Mr. Freeman holds the degrees of bachelor of science in electrical engineering and master of science in physics from Washington University.

I. E. McDougal (A '40) formerly lieutenant, United States Naval Reserve, attached to the Army–Navy Munitions Board, Washington, D. C., has been appointed apparatus sales manager for the Electric Supplies Distributing Company, San Diego, Calif. Mr. McDougal also served aboard an aircraft carrier.

OBITUARY • • • •

Richard Harold Dearborn (A '07, M '14, F '30) dean emeritus of engineering, Oregon State College, Corvallis, died March 21, 1946. Dean Dearborn was born November 2, 1874, in Salem, Oreg., and was graduated from Willamette University with the degree of bachelor of arts in 1895 and from Cornell University with the degree of mechanical engineer in electrical engineering in 1900. After a year with the Portland (Oreg.) General Electric Company, he joined the faculty of the University of Oregon, Eugene, in 1901. The following year he established the department of electrical engineering and continued as head of the department until 1914. He served as electrical engineer on the Oregon State Tax Commission in 1911 and on the Public Service Commission of Oregon from 1913 to 1915. From 1914 to 1933 he was head of the department of electrical engineering at Oregon State College and in 1933 was named dean of engineering. He was director of engineering, science, and management war training for the college from 1940 until his retirement in 1944. He was a member of the Society for the Promotion of Engineering Education, the Northwest Electric Light Power Association, the Corvallis Chamber of Commerce, Tau Beta Pi, Sigma Tau, and Eta Kappa Nu.

Francis Leslie Stevenson (A '03, M '21) retired superintendent of steam and power, International Harvester Company, Chicago, Ill., died February 13, 1946. Mr. Stevenson was born February 7, 1866, in Detroit, Mich., and was graduated from the University of Michigan in 1888. Later he attended the Chicago Law School. He was in the engineering department of the Thomson-Houston Electric Company and the General Electric Company in Lynn and Boston, Mass., in Chicago, and in Pittsburgh, Pa., from 1886 to 1893. He took charge of the electrical department of the Consolidated Street Railway Company, Grand Rapids, Mich., in 1894 and left that position in 1897 to join the Deering Harvester Company which later became the Deering division of the International Harvester Company. After 1905 he was associated with the International Harvester Company as chief electrical engineer, electrical and power engineer, and supervisor of steam and power. Much of his work was concerned with power applications to manufacturing and to steel mill and coal mining operations. He was a member of the American Association for the Advancement of Science and of the Bar of the State of Michigan.

Louis Shapiro (A '36) engineer in the electrical department, Cox and Stevens, New York, N. Y., died April 28, 1946. Mr. Shapiro was born September 10, 1893, in New York, attended Cooper Union, and was graduated from the Hebrew Technical Institute. From 1911 to 1917 he was associated with the New York Edison Company, doing engineering testing for central stations, laboratory work on substations, and statistical work. During World War I he was a second lieutenant in heavy artillery. After the war he spent a year with the Cutler-Hammer Company, and a year with T. E. Murray, Inc., both in New York. He returned to the New York Edison Company in 1921 and remained with that company until 1930 as squad leader, designer, and field supervisor on construction. He was ventilation designer with the New York City Board of Transportation from 1930 to 1932. He rejoined the Edison company in 1936 and became an estimator for Fischbach and Moore, New York, in 1937, and in 1940 electrical designer for the Public Service Electric and Gas Company, Newark, N. J. He had been with Cox and Stevens since 1944.

Edward Byron Elliott (A '17, M '27) engineering department, the Solvay Process Company, Syracuse, N. Y., died March 14, 1946. Mr. Elliott was born January 17, 1886, in Hillsboro, Ohio, and attended Ohio University. He completed an apprenticeship course with the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., in 1910 and was attached to the company's Buffalo (N. Y.) district sales office from 1910 to 1912. He joined the Semet-Solvay Company, Syracuse, in 1912 as a member of the staff of the mechanical engineer, was transferred to the staff of the general superintendent in 1918, and was named power engineer in 1922. He was associated with the firm of Stone and Webster, Boston, Mass., from 1924 to 1932, and with the Forstmann Woolen Company, Passaic, N. J., from 1932 to 1934. Since 1934 he had been design engineer with the Solvay Process Company. Mr. Elliott was a member of the Syracuse Technology Club and the Association of Iron and Steel Engineers.

Edgar George Scott (A '10, M '17) consulting engineer, Campbell Soup Company, Moorestown, N. J., died December 25, 1945. Born in Worcester, Mass., in 1882, Mr. Scott was graduated from Worcester Polytechnic Institute in 1905 and received the degree of electrical engineer in 1907. In 1905 he became electrical apprentice for the Westinghouse Electric and Manufacturing Company for one year. He spent two and one half years each with the Boston Elevated Railway and with the consulting firm of N. J. Neall, Boston. He joined the Boott Mills, Lowell, Mass., in 1912 and the Ludlow Manufacturing Association as superintendent of power and repairs in 1913. He was appointed chief engineer of the Campbell Soup Company, Camden, N. J., in 1917 and retired to the position of consulting engineer in 1940. Mr. Scott was a member of the American Society of Mechanical Engineers. He was consulting engineer in the laying out of Strawbridge Park in Moorestown.

Edward L. Adams (A '24) engineer, the Kerite Company, Chicago, Ill., died May 4, 1946. Mr. Adams was born December 1, 1876, in Ashland, Mass., and was graduated from Brown University in 1898 with the degree of mechanical engineer. Mr. Adams commenced his career in the armature department of the General Electric Company, Schenectady, N. Y., and in 1899 entered the electrical engineering department of the Boston (Mass.) Elevated Lines. He was chief signal inspector and assistant signal engineer with the Boston and Albany Railroad from 1902 to 1914. He was senior railway signal engineer with the Interstate Commerce Commission from 1914 until in 1917 he became a captain in the Corps of Engineers and served overseas. After a year with the United States Railroad Administration in 1919, he joined the Kerite Company as sales engineer.

Leon A. Watson (M '35) vice-president in charge of engineering research and development, Clark Controller Company, Cleveland, Ohio, died April 18, 1946. Mr. Watson, who was born August 19, 1887, in Yorktown, N. J., was graduated from Syracuse University in 1910 with the degree of electrical engineer. From 1910 to 1912 he was in the engineering department of the National Electric Lamp Association, Cleveland, and in 1912 joined the Electric Controller and Manufacturing Company, Cleveland, as draftsman and became assistant chief engineer in 1924. In 1925 he helped organize the Clark Controller Company of which he was made chief engineer. For a number of years he was vice-president and chief engineer, and in 1944 he was named vice-president in charge of research and development. He was a member of the AIEE committee on industrial control devices.

Samuel Robert Blair (A '29) assistant chief engineer, Bowater's Newfoundland Pulp and Paper Mills, Corner Brook, died April 17, 1946. Mr. Blair was born October 18, 1893, in Limerick, Ireland. He served as an apprentice for the Limerick Gas and Electric Company from 1910 to 1912. In 1913 he was employed as electrician by the Dominion Bridge Company and the Grand Trunk Railway Company, both of Montreal, Quebec, Canada. He was with the Canadian Pacific Railway Company, Montreal, as electrician from 1914 to 1928. In 1928 he went to Newfoundland as electrical superintendent for the International Power and Paper Company, Corner Brook. He joined the Bowater's mills as electrical superintendent in 1939 and was appointed assistant chief engineer in 1944.

Aubrey Ramon Curry (M '34) electrical engineer, Buffalo (N. Y.), Niagara and Eastern Power Corporation, died February 6, 1946. Born February 12, 1899, in Nassau, Bahamas, B. W. I., Mr. Curry was graduated from London University in 1920 and received the degree of electrical engineer from Cornell University. After completing the graduate student course at the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., in 1921, he became a general tester for the New York (N. Y.) Edison Company. He was junior electrical engineer with the Chile Exploration Company from 1922 to 1924 and in 1924 entered the employ of the Buffalo Niagara company as electrical engineer.

John Harkins (A '21, M '39) district planning engineer, electrical engineering department, Hydro-Electric Power Commission of Ontario, Toronto, Canada, died May 21, 1946. Born in Toronto, September 13, 1896, Mr. Harkins was graduated from the University of Toronto with the degree of bachelor of science in electrical engineering in 1919. Before joining the Hydro-Electric Power Commission in 1921 as electrical draftsman, he was electrical engineer with the Dunlop Tire Company, Toronto. He was made assistant engineer in 1925 and system planning engineer in 1939. Mr. Harkins had taught in the evening classes of the Central Technical High School of Toronto since 1919.

Robert Butterfield Trench (A '41) plant engineer, New York Telephone Company, New York, died April 21, 1946. Mr. Trench was born January 13, 1909, in Chillicothe, Ohio, and was graduated from the Sheffield Scientific School *magna cum laude* in 1929. That same year he joined the New York Telephone Company as engineering assistant and in 1932 became switchman. He was titled installer in 1937 and engineer in 1941. In 1944 he became plant engineer. Mr. Trench was a member of Sigma Xi.

W. L. Chambers (A '45) salesman, Charleston (W. Va.) Electrical Supply Company, died May 18, 1946. Mr. Chambers was born in Spencer, W. Va., in 1904. He had been in the sales department of the Electrical Supply company since 1926. For the past seven years he had charge of all lighting and sales engineering of lighting equipment handled by the company.

MEMBERSHIP ••

Recommended for Transfer

The board of examiners, at its meeting of June 20, 1946, recommended the following members for transfer to the grade of membership indicated. Any objections to these transfers should be filed at once with the secretary of the Institute.

To Grade of Fellow

Claytor, G., operating vice-pres., American Gas & Elec. Serv. Corp., New York, N. Y.
Perry, W. W., chief engr., New York State Elec. & Gas Corp., Binghamton, N. Y.
Peterson, W. S., asst. chief elec. engr., Dept. of Water & Pr., Los Angeles, Calif.
Thompson, G., chief engr., Electrical Testing Labs., Inc., New York, N. Y.
Wright, R. H., steel mill engr., Westinghouse Elec. Corp., E. Pittsburgh, Pa.

5 to grade of Fellow

To Grade of Member

Baltzell, L. A., genl. supt., plains div., Southwestern Public Serv. Co., Plainview, Tex.
Barden, W. A., U. S. Army Air Forces, Air Technical Intelligence, Wright Field, Dayton, Ohio.
Bergmann, W. F., asst. elec. engr., Public Utility Engg. & Serv. Corp., Chicago, Ill.
Caminetti, P. A., cons. engr., 45-18 Court Square, Long Island City, N. Y.
Christensen, C. P., engr., Illinois Bell Tel. Co., Chicago, Ill.
Coddington, R. W., elec. engr., Bonneville Pr. Adm., Portland, Oreg.
Connolly, W. T., sr. engr., Idaho Pr. Co., Boise, Idaho.
Cooper, L. S., advance design & div. engr., General Elec. Co., Erie, Pa.
Criley, W., engr., equip. engg. div., Rochester Tel. Corp., Rochester, N. Y.
Dlouhy, F. S., relay engr., Oklahoma Gas & Elec. Co., Oklahoma City, Okla.
Egeberg, H., chief engr., State Electricity Comm., Queensland, Australia.
Embry, A. L., design engr., General Elec. Co., Lynn, Mass.
Enriquez, O. R., head, hydroelectric div., Comision Nacional De Irrigacion, gen'l. director, Secretaria Economia Nacional, Mexico, D. F., Mexico.
Evans, W. M., elec. engr., testing & drafting depts., U. S. Electrical Motors, Inc., Los Angeles, Calif.
Fairley, R. K., development engr., General Elec. Co., Schenectady, N. Y.
Garlington, W. L., elec. engr., Reynolds, Smith & Hills, Jacksonville, Fla.
Gause, H. H., Jr., chief elec. engr., Nantahala Pr. & Lt. Co., Franklin, N. C.
Greentree, C. D., section engr., general engg. & cons. lab., General Elec. Co., Schenectady, N. Y.
Grosh, F. R., asst. to vice-pres., Portland General Elec. Co., Portland, Oreg.
Hacussler, F. B., asst. dist. engr., General Elec. Co., Boston, Mass.
Henderson, W. A., outside plant engr., New York Tel. Co., New York, N. Y.
Jackson, F. R., Jr., elec. engg. designing, General Elec. Co., Pittsfield, Mass.
Karr, J. H., asst. chief engr., Robbins & Myers, Inc., Springfield, Ohio.
Koontz, R. E., elec. engr., National Standard Co., Niles, Mich.
Kratzer, R. E., engr., Detroit Edison Co., Detroit, Mich.
Livingston, J. M., sales engr., G. & W. Elec. Specialty Co., Chicago, Ill.
Lloyd, L. H., project engr., Air Matériel Command, Wright Field, Dayton, Ohio.
MacLean, T. W., communications engr., Washington Water Pr. Co., Spokane, Wash.
Mohns, J. C., sr. elec. engg. draftsman, Public Utilities Engg. Bureau, San Francisco, Calif.
Morrison, W. J., elec. engr., Prudential Insurance Co. of America, Newark, N. J.
Noller, W. E., engr., Pacific Tel. & Tel. Co., San Francisco, Calif.
Northrup, M. G., prof. & head, dept. of elec. engg., Speed Scientific School, Univ. of Louisville, Louisville, Ky.
Plucknett, K. J., assoc. engr., U. S. Dept. of Agric., Rural Electrification Adm., Washington, D. C.
Reber, J. F., ind. elec. engg. specialist, Westinghouse Elec. Intl. Co., New York, N. Y.
Rokicki, A. J., engr., New York Tel. Co., Albany, N. Y.
Rock, J. J., elec. engr., Giddings & Lewis Machine Tool Co., Fond du Lac, Wis.
Silvus, W. E., engr., General Elec. Co., Houston, Tex.
Smedley, G. B., sr. engr., Commonwealth Edison Co., Chicago, Ill.
Sterner, E. E., engr., Tennessee Eastman Corp., Oak Ridge, Tenn.
Stevenson, W. D., Jr., asst. prof., elec. engg., Princeton Univ., Princeton, N. J.
Streed, E. R., asst. operating engr., Delaware Pr. & Lt. Co., Wilmington, Del.
Stringfield, T. W., elec. engr., Bonneville Pr. Administration, Portland, Oreg.
Stuart, R. M., research engr., Harvey-Wells Electronics, Inc., Southbridge, Mass.
Tatum, G. M., supervisor of elec. equip. & trans., Virginia Elec. & Pr. Co., Richmond, Va.
Thompson, R. P., engr., Southern California Tel. Co., Los Angeles, Calif.
Wagstaff, R. R., elec. engr., United Engineers & Constructors, Inc., Philadelphia, Pa.
Wantland, J. S., asst. meter supervisor, Oklahoma Gas & Elec. Co., Oklahoma City, Okla.
Wanttelius, O. G., engr., General Elec. Co., Schenectady, N. Y.
Wynn, J. H., Captain, U. S. Army Signal Corps, 330 Sherman St., Watertown, N. Y.

49 to grade of Member

Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. Any member objecting to the election of any of these candidates should so inform the secretary before August 15, 1946, or October 15, 1946, if the applicant resides outside of the United States or Canada.

To Grade of Member

Backer, L. A., Richwood Place, Denville, N. J.
Bailey, B. F., Jr., Commonwealth and Southern Corp., Jackson, Mich.
Beardmore, A. E., General Elec. Co., Schenectady, N. Y.
Blades, J. M., Barbados Elec. Supply Corp., Ltd., Barbados, British West Indies
Borokhovich, J. A. (Re-election), Consolidated Edison Co. of N. Y. Inc., Brooklyn, N. Y.
Boyum, L. L., Westinghouse Elec. Corp., Minneapolis, Minn.
Braden, C. E., Ebasco Services, Inc., New York, N. Y.
Chadwick, G. A., Vickers Inc., Detroit, Mich.
Codd, W. A., Stromberg-Carlson Co., Rochester, N. Y.
Crow, R. B., Bonneville Pr. Administration, Pittsburgh, Pa.
Dakin, J. B., Sr., General Motors Corp., Lansing, Mich.
Dey, C., General Elec. Co., Philadelphia, Pa.
Downie, J. M., General Elec. Company, Erie, Pa.
Ghen, R. C., Boston Edison Co., Boston, Mass.
Goodwin, R. H., Birlec, Ltd., Birmingham, England
Griffiss, M. E., Automatic Elec. Co., Chicago, Ill.

Harker, R. M., Youngstown Municipal Railways Co., Youngstown, Ohio
Hartman, M. E., General Elec. Co., Schenectady, N. Y.
Hildebrandt, L. H., Air Matériel Command, Wright Field, Dayton, Ohio
Hoefle, A., The Toledo Edison Co., Toledo, Ohio
Jenkins, H. M., Swarthmore College, Swarthmore, Pa.
Joslon, F. P., Consolidated Edison Co. of N. Y., New York, N. Y.
Katzer, H., Cia. Auxiliar de Empresas Electricas Brasileiras, Rio de Janeiro, Brazil, S. A.
King, R. B., Automatic Elec. Co., Chicago, Ill.
Kucej, L., Shanghai Pr. Co., Shanghai, China.
Lingel, F. J., The Triplett Elect. Inst. Co., Bluffton, Ohio
Lowe, H. F., Sloan Cook & Lowe, Chicago, Ill.
Machen, C. P., Boston Consolidated Gas Co., Boston, Mass.
Maia, D. F. A., Central of Brasil Railroad, Rio de Janeiro, Brazil, S. A.
Manley, J. M., Bell Tel. Labs., Murray Hill, N. J.
McAllister, Carl J. Kiefer Associates, Inc., Cincinnati, Ohio
McBrearty, J. J., Pennsylvania Pr. & Lt. Co., Shenandoah, Pa.
Miller, S. E., American Bosch Corp., Springfield, Mass.
Mosteller, W. A., General Elec. Co., Detroit, Mich.
Murray, P. E., General Elec. Co., Cleveland, Ohio
Nock, N. T., Birlec Ltd., Glebe, N. S. W., Australia
Oakhill, F. E., O-Cedar Corp., Chicago, Ill.
Peters, H. P., Westinghouse Elec. Corp., East Pittsburgh, Pa.
Pew, R. M., American Tel. & Tel. Co., Philadelphia, Pa.
Rice, F. S., Minnesota Pr. & Lt. Co., Duluth, Minn.
Potter, F. M., Sperry Gyroscope Co., Inc., Great Neck, N. Y.
Rombach, J. R., Jr., New Orleans Public Service, Inc., New Orleans, La.
Sear, R. V., Cia. Colombiana de Electricidad, Barranquilla, Colombia, S. A.
Seastone, J. B., Westinghouse Elec. Corp., E. Pittsburgh, Pa.
Sehgal, K. L., Delhi Polytechnic, Delhi, India
Shaheen, J., Sylvania Elec. Products, Inc., Ipswich, Mass.
Stoetzel, D., Jr., General Elec. Co., Schenectady, N. Y.
Van Etten, A. L., U. S. Navy Dept., Washington, D. C.
Way, J. S., Commonwealth Edison Co., Chicago, Ill.
Westgard, B. E., A. C. M. Co., Anaconda, Mont.
Westman, H. P., Sr., Int'l Tel. & Tel. Corp., New York, N. Y.
Will, E. H., El Paso Electric Co., El Paso, Tex.
Wilson, E. F., Houston Lighting & Pr. Co., Houston, Tex.

53 to grade of Member

To Grade of Associate

United States and Canada

1. NORTH EASTERN

Blanchet, O. J. (Re-election), 91 Jouvette St., New Bedford, Mass.
Buttner, B. W., Eastman Kodak Co., Kodak Park, Rochester, N. Y.
Clark, O. D., General Elec. Supply Corp., Boston, Mass.
Dietrich, H. H., Rochester Products Co., Rochester, N. Y.
Easton, E. P., Jr., Allis-Chalmers Mfg. Co., Boston, Mass.
Forbes, E. C., Int'l General Elec. Co., Schenectady, N. Y.
Hansell, E. B., General Elec. Co., Schenectady, N. Y.
Hoelle, L. C., General Elec. Co., Pittsfield, Mass.
Johnson, L. J., General Elec. Co., Schenectady, N. Y.
King, J. H., New England Pr. Service Co., Boston, Mass.
Kopach, S., General Elec. Co., Schenectady, N. Y.
Krieger, E. T., Int'l General Elec. Co., Schenectady, N. Y.
Pafenbach, W. M. (Re-election), General Elec. Co., Pittsfield, Mass.
Pruett, H. C., General Elec. Co., Schenectady, N. Y.
Robertson, J. W., General Elec. Co., Schenectady, N. Y.
Race, H. G., Kenworthy & Taylor, Inc., Everett, Mass.
Rogers, E. K., Scovill Mfg. Co., Waterbury, Conn.
Schroeter, C. E., U. S. Rubber Co., Naugatuck, Conn.
Scudder, R. E., Allis-Chalmers Mfg. Co., Providence, R. I.
Sutton, W. I., General Elec. Co., Schenectady, N. Y.
Wallis, T. M., Jr., General Elec. Co., Lynn, Mass.
Wargin, E. F., General Elec. Co., Schenectady, N. Y.
Wohlwill, H. E., Corning Glass Works, Corning, N. Y.

2. MIDDLE EASTERN

Berger, F. L., Jr., Westinghouse Elec. Corp., Lima, Ohio
Booher, R. E., The Ohio Brass Co., Mansfield, Ohio
Brown, R. M., AAF, Wright Field, Dayton, Ohio
Crafton, B. L., American Tel. & Tel. Co., Philadelphia, Pa.
Cranmer, E. P., Public Service Elec. Co., Camden, N. J.
Craven, F. T., John A. Roebling's Sons Co., Philadelphia, Pa.
Cruess, W. F., Westinghouse Elec. Corp., E. Pittsburgh, Pa.
Donaldson, C. (Re-election), Briggs Filtration Co., Bethesda, Md.
Dyer, V. M., Westinghouse Elec. Corp., Washington, D. C.
Fink, J. C., Westinghouse Elec. Corp., E. Pittsburgh, Pa.
Foulds, J. T., The Phila. & Reading Coal & Iron Co., Pottsville, Pa.
Freidline, D. R., Dayton Pr. and Lt. Co., Dayton, Ohio
Hammond, C. E., Westinghouse Elec. Corp., East Pittsburgh, Pa.
Hart, J. P., Philadelphia Elec. Co., Doylestown, Pa.
Herman, J., Naval Ordnance Lab., Navy Dept., Washington, D. C.
Hogan, D. L., National Bureau of Standards, Washington, D. C.
Jackson, D. W., David Taylor Model Basin, Washington, D. C.
Lawrence, W. L., Westinghouse Elec. Corp., E. Pittsburgh, Pa.
Lewis, F. W., General Elec. Co., Philadelphia, Pa.
Lightfoot, E. B., The Chesapeake & Potomac Tel. Co., Washington, D. C.
Nelson, L. E., West Penn Pr. Co., Pittsburgh, Pa.
Oman, H. T., 870 E. McCreight Ave., Springfield, Ohio
Rector, R. E., Westinghouse Elec. Corp., E. Pittsburgh, Pa.
Rondell, L. F., Mansfield Tire & Rubber Co., Mansfield, Ohio
Schall, R. F., Roller-Smith, Bethlehem, Pa.
Smart, J. E., The Hertner Elec. Co., Cleveland, Ohio
Yingst, P. V., 2634 Jefferson St., Harrisburg, Pa.
Young, J. C., Day & Zimmermann Inc., Philadelphia, Pa.

3. NEW YORK CITY

Boyle, G. G., Lt. (jg), USNR, 151 West Third St., Bayonne, N. J.
Cowan, J. H., The Kerite Co., New York, N. Y.
Davis, D. M., U. S. Navy, c/o FPO, New York, N. Y.
Dixon, E. G., General Elec. Co., New York, N. Y.
Guise, F. A., United Fruit Co., New York, N. Y.
Harris, H., Jr., Sperry Gyroscope Co., Great Neck, N. Y.
Hayes, A. E., Industrial Electronics Corp., Newark, N. J.
Kaeser, F. L., Frederic R. Harris, New York, N. Y.
McGeeney, J. J., New York Tel. Co., Brooklyn, N. Y.
Morris, A. M., Westinghouse Elec. Int'l. Co., New York, N. Y.
Patterson, R. B., New Jersey Bell Tel Co., Jersey City, N. J.
Potter, G. R., Ebasco Services, Inc., New York, N. Y.
Rynkowsky, N., 2886 Briggs Avenue, New York, N. Y.
Smith, D. P., Brooklyn Law School, Brooklyn, N. Y.

4. SOUTHERN

Axbell, R. A., E. Barrett Foster, Sheffield, Ala.
Bailey, H. T., Jr., Louisiana Pr. and Lt. Co., Gretna, La.
Caldwell, S. Y., Jr., Alabama Pr. Co., Birmingham, Ala.
Cox, J. C., Norfolk Naval Ship Yard, Portsmouth, Va.
Ivey, A. J., Alabama Pr. Co., Birmingham, Ala.
Jones, W. C., Nashville Elec. Serv., Nashville, Tenn.
Markli, F. A., 3rd, Tennessee Eastman Corp., Oak Ridge, Tenn.
McCanahan, H. C., TCI & RR Co., Fairfield Steel Works, Fairfield, Ala.
Myers, F. B., Southern States Equip. Corp., Hampton, Ga.
Myers, R. G., Alabama Pr. Co., Birmingham, Ala.
Newton, R. E., Southern Bell Tel. & Tel. Co., Louisville, Ky.
Talcott, T. W., Southern Bell Tel. & Tel. Co., Louisville, Ky.

5. GREAT LAKES

Baker, G. E., Illinois Pr. Co., Belleville, Ill.
Barstow, F. E., Consumers Pr. Co., Manistee, Mich.
Belcher, T. H., Michigan Bell Tel. Co., Detroit, Mich.
Bloor, W. S., Leeds & Northrup Co., Chicago, Ill.
Bruya, F. C., Jr., General Elec. Co., Fort Wayne, Ind.
Carson, N. R., Commonwealth Edison Co., Chicago, Ill.
Cliff, R. A., General Elec. Co., South Bend, Ind.
Christensen, C., Automatic Elec. Co., Chicago, Ill.
Davis, C. M., The Detroit Edison Co., Detroit, Mich.
Dunn, D. F., Westinghouse Elec. Corp., Minneapolis, Minn.
Dunn, E. C., Sampsel Time Control, Inc., Spring Valley, Ill.
Hammond, H. G., The Detroit Edison Co., Detroit, Mich.
James, S. W., Allis-Chalmers Mfg. Co., Milwaukee, Wis.
Knapp, William W., Aluminum Co. of America, Minneapolis, Minn.
LaSere, E. I., Northern States Pr. Co., Minneapolis, Minn.
LeBold, W. K., Automatic Elec. Co., Chicago, Ill.
Lecher, E. A., Allis-Chalmers Mfg. Co., Milwaukee, Wis.
Markland, H. J., Public Serv. Co. of Ind., Inc., Indianapolis, Ind.
Plasmier, G. C., Automatic Elec. Co., Chicago, Ill.
Simonson, B., Automatic Elec. Co., Chicago, Ill.
Smith, V. C., Consumers Pr. Co., Grand Rapids, Mich.
Stevenson, H. R., The Detroit Edison Co., Detroit, Mich.
Vanderberg, L. J., King-Seeley Corp., Ann Arbor, Mich.
Vitulli, A. F., Underwriter's Labs., Inc., Chicago, Ill.
Waller, M. S., Automatic Elec. Co., Chicago, Ill.
Williams, R. T., Automatic Elec. Co., Chicago, Ill.
Zalewski, H. F., Dept. of Subways & Superhiways, Chicago, Ill.

6. NORTH CENTRAL

Edmonds, H. M., Public Service Co. of Colo., Denver, Colo.
Glea, G. E., Jr., University of Colo., Boulder, Colo.
Waggoner, W. M., Bureau of Reclamation, Denver, Colo.

7. SOUTH WEST

Brush, C., American Tel. & Tel. Co., Dallas, Tex.
Cassil, C. C. (Re-election), S. W. Bell Tel. Co., Houston, Tex.
Caswell, W. H., Gulf States Utilities Co., Beaumont, Tex.
Cole, J. H., 323 N. W. Second Street, Oklahoma City, Okla.
Fullwood, W. A., Jr., S. W. Marshall, Jr., Dallas, Tex.
Joseph, C. E., Peterson & MacFayen, Little Rock, Ark.
Peters, B., University of Kansas, St. Joseph, Mo.
Robinson, K. G., Beech Aircraft Corp., Wichita, Kan.
VanBurkleo, G. R., Public Service Co. of Okla., Tulsa, Okla.
Van Buskirk, T. E., Ens., USNR, 5418 St. John, Kansas City, Mo.
Whitmore, W. D., Todd Galveston Dry Docks, Inc., Galveston, Tex.
Woodson, J. J., Capt., U.S.A., 422 South Smith St., Vinita, Okla.

8. PACIFIC

Austin, H. C., Southern Calif. Edison Co., Ltd., Los Angeles, Calif.
Beckhorn, W. H., Clyde E. Bentley, San Francisco, Calif.
Creighton, L. L., Pacific Gas & Elec. Co., San Francisco, Calif.
Doak, W. M., Basic Magnesium Project, Henderson, Nev.
Gregory, G. W., Jr., Ens., USNR, DirEastPacDocks, San Francisco, Calif.
Haley, W. H., Jr., General Elec. Co., San Francisco, Calif.
Johnson, E. F., U. S. Navy, c/o F.P.O., San Francisco, Calif.
Ledyard, D. B., Pasadena Lt. & Pr., Pasadena, Calif.
Lighthipe, J. A., Southern Calif. Edison Co., Anaheim, Calif.
Mielecki, C. A., C. F. Braun & Co., Alhambra, Calif.
Mobley, C. L., Tucson Gas, Elec. Lt. & Pr. Co., Tucson, Ariz.
Ninnis, G. E., Kurze Electrical Works, San Jose, Calif.
Potter, J. B., U. S. Navy Supply Depot, San Pedro, Calif.

9. NORTH WEST

Derrick, G. R., U. S. Bureau of Reclamation, Salt Lake City, Utah
Johnston, R. W., Lake Washington Shipyards, Houghton, Wash.
Lehl, H. G., General Elec. Supply Corp., Portland, Oreg.
McHenry, G. A., Boeing Aircraft Co., Seattle, Wash.
Moats, W. L., Westinghouse Elec. Corp., Salt Lake City, Utah
Mortell, R. P., Puget Sound Pr. & Lt. Co., Seattle, Wash.
Radin, C. J., DeWitt C. Griffin & Associates, Seattle, Wash.

10. CANADA

Ainsworth, H., Dominion Govt., Ottawa, Ontario, Canada
Asselstine, J. J., Falconbridge Nickel Mines, Falconbridge, Ontario, Canada
Fetherston, L. C., Canadian Westinghouse Co., Hamilton, Ont. Canada
Kaupp, F. R., Kaupp Elec., Merritton, Ontario, Canada
Wenger, G. R., T. Pringle & Son, Ltd., Montreal, Quebec, Canada

Elsewhere

Booth, H., Messrs. McLellan & Partners, Glamorganshire, South Wales, Great Britain
Campos, C. A., Empresas Unidas de Energia Electrica, Bogota, Colombia, S. A.
Chiang, F. Y. K., Sung Sing Cotton Mill No. 9, Shanghai, China
Davis, E. R., Herring & Bostwick, Ltd., Bulawayo, Rhodesia, South Africa
Fu, C. S., Metropolitan-Vickers Electrical Co., Ltd., Manchester, England
Rollo, J. T., Southern Electricity Supply of New South Wales, Goulborn, N. S. W. Australia
Strauven, M. J. J., Societe Generale des Forces Hydro-electriques du Katanga (Congobelge), Brussels, Belgium

Total to grade of Associate

United States and Canada, 144
Elsewhere, 7

OF CURRENT INTEREST

EJC Joins Campaign for Books for War-Damaged Libraries

The Engineers Joint Council, representing five national engineering societies has combined with the American Book Center for War Devastated Libraries, Inc., in efforts to help restore engineering and other libraries overseas. The American Book Center, which has its headquarters in the Library of Congress, Washington, D. C., will be the central handling point for volumes contributed through the engineering societies and will receive, sort, assign, pack, and ship the books.

With this action, the Engineers Council renewed its recent appeal for engineering books and technical literature. Contributors are asked first to send a list of the books they wish to donate to the Chairman of Book Commission, Engineers Joint Council, 29 West 39th Street, New York 18, N. Y. Shipping instructions and bookplates then will be sent them. Gifts of money will be used by the committee to purchase new books for special needs.

As shipping facilities are limited and demand that all materials be selected carefully, the following listing of what is and what is not needed has been prepared:

What Is Needed. Emphasis is placed upon publications issued during the past decade, upon scholarly books which are important contributions to their fields, upon periodicals (even incomplete volumes) of significance, upon fiction and nonfiction of distinction. All subjects—history, the social sciences, music, fine arts, literature, and especially the sciences and technologies —are wanted.

What Is Not Needed. Textbooks, outdated monographs, recreational reading, books for children and young people, light fiction, materials of purely local interest, popular magazines such as *Time, Life, National Geographic*, popular nonfiction of little enduring significance. Only carefully selected federal and local documents are needed, and donors are requested to write directly to the center with regard to specific documents.

The co-operative arrangement, officially approved by the American Book Center and by the Engineers Joint Council, is expected to aid the efforts of both materially. The American Book Center works closely with the Department of State and is recognized by foreign countries. It enjoys shipping privileges and priorities which facilitate deliveries abroad. The United Nations Relief and Rehabilitation Administration is convinced that these programs are so directly related to reconstruction of devastated countries that it is providing shipping space.

The EJC Committee on International Relations, headed by Malcolm Pirnie, is carrying on the effort for the engineers. It represents the American Society of Civil Engineers, American Institute of Mining and Metallurgical Engineers, The American Society of Mechanical Engineers, American Institute of Electrical Engineers, and American Institute of Chemical Engineers.

Since the campaign got under way a few months ago, under direction of a Committee on International Relations of the ASME, with other societies participating, considerable progress has been made. A special purchase of books on management has been made for the Masaryk Academy in Prague, Czechoslovakia. More than 100 individual offers of technical books and other literature have been received, but shipping difficulties caused delay until the recently completed arrangement with the American Book Center.

Twelve of the country's leading library groups sponsor the American Book Center for War Devastated Libraries, Inc. They include the American Library Association, and the associations of law, college and reference, medical, research, children's libraries, and other groups.

Kenneth R. Shaffer is the executive director of the American Book Center. The work was started in February 1945, with 20 countries originally benefiting. A few weeks ago 14 more countries were added, financed by the Rockefeller Fund. About 5,000 libraries are beneficiaries.

The material is allocated to countries and institutions where it will be most helpful. Donors therefore are asked not to designate the country to receive their books. Shipping costs must be prepaid, but when requested by the donor, the sum will be refunded, although it is hoped that generally the donor will bear the shipping cost.

In a recent appeal for books, Mr. Shaffer said:

During the war, the libraries of half the world were destroyed in the fires of battle and in the fires of hate and fanaticism. Where they were spared physical damage, they were impoverished by isolation. There is an urgent need—now—for the printed materials which are basic to the reconstruction of devastated areas and which can help to remove the intellectual blackout of Europe and the Orient.

This 4 by 5½ inch bookplate which will be sent to contributors was designed specially for the book drive by G. H. Kuechler

Included in the 34 benefiting countries are some whose libraries, as in Holland, were not seriously damaged, but were completely shut off from current publications. These 34 countries are:

Full participants: Belgium, Burma, China, Finland, Greece, Italy, Luxembourg, Netherlands, Norway, Poland, Siam, Yugoslavia.

Limited participation: Czechoslovakia, Denmark, England, France, Philippines, Soviet Union, Austria, Romania, Hungary, Bulgaria, Sweden, Switzerland, Spain, Portugal, Australia, New Zealand, India, Egypt, Turkey, Korea, Germany, and Japan.

Typical in its appeal was a letter received recently from the Philippines, addressed to the ASME. It read:

At the outbreak of World War II, the Scientific Library of the Bureau of Science, an office under this Department, had one of the largest and best known collections of technical and scientific publications in this part of the Orient. This same library was destroyed by the Japanese during the war. We shall appreciate it, therefore, if you will kindly help us in the task of building anew from scratch some such collection by donating to the library whatever publications you can spare now and in the future.

Electrical Manufacturing Threatened by Copper Shortage

Acute shortages of copper, due to strikes in the copper mining, smelting, refining, and fabricating industries, which have been slowly paralyzing the electrical manufacturing industry, soon will force widespread plant curtailment and shutdowns, according to R. L. White, president of the National Electrical Manufacturers Association, following a poll taken at a meeting of the board of governors of the association held on June 7.

The seriousness of the copper situation already is being experienced by the public, because of the lack of copper and brass components, which prevent the shipping of otherwise completed household appliances, Mr. White pointed out. Unless the situation is relieved immediately, he said, many electric appliance dealers will be forced into bankruptcy. Housing projects also will be hamstrung for the lack of wire, cable, and electric building materials, he said.

The shortage of wire bars is particularly acute, and an estimate was made that the Government held about 1,000 tons of such bars at the end of May, against a monthly consumption by the industry of about 60,000 tons. Perhaps the maximum distribution by the Government in sight for June would be 10,000 tons. This, with limited imports of copper allowed by the Government, in no way would meet the demand.

Shortage of Young Engineers Will Exist Until 1949

In November 1945, engineering student enrollment in the United States and Canada was 73,269. However, this number will not remedy greatly the 150,000 deficit in engineers reported by Vannevar Bush, (F '24) director of the United States Office of Scientific Research and Development. It is probable that about 5,000 degrees in engineering will be conferred this coming June. Although a slight increase over last year, this figure is only 30 per cent of the peak number of degrees conferred in 1942–43.

William B. Plank, head of the department of mining and metallurgical engineering of Lafayette College, Easton, Pa., states in the May issue of *Mining and Metallurgy* that "Undoubtedly, anything like a normal supply of engineering graduates will not occur until the present freshman class is graduated in 1949."

Professor Plank estimates that the second semester engineering enrollment will be about 100,000 with the bulk of this increase coming from the enrollment of veterans. "The great danger here is that some institutions may be exceeding their proper capacity to handle this abnormally large enrollment all in one class. The results of this crowding, which now principally affects living quarters, will be much more acute in the departmental laboratories when the men reach their third and fourth years."

Professor Plank's statistics show that some 949 electrical engineers were graduated in June 1946, in addition to 289 mineral engineers, 748 chemical engineers, 714 civil engineers, 1,373 mechanical engineers, and 898 engineers of other types. These figures do not include the engineers now enrolled in graduate work who will enter the industrial field this spring.

Government Contracts for Atomic Energy Development

The War Department recently announced a contract with the General Electric Company under which the latter will take over operation of the Government's $347,000,000 plant at Hanford, Wash., about September 1, for an "extensive research program" in atomic energy.

During the war the plant was operated by E. I. du Pont de Nemours and Company, Inc., which is retiring from the program because the peacetime aspects lie primarily in the field of power generation and not in the chemical field which is the du Pont company's main concern.

The General Electric Company, President Charles E. Wilson explained, is assuming responsibility for the plant's operation because with the company's background of prewar atomic research, it is convinced that "the greatest possible development of nonmilitary application, not only is the most constructive solution to the problem which atomic energy presents to the world, but also the greatest opportunity for more jobs and more goods for more people in the future.

The Hanford works will be operated by a manager with an advisory committee consisting of H. R. Winne (F '45) vice-president in charge of engineering policy, C. G. Suits (M '41) vice-president and director of the research laboratories, and Zay Jeffries (F '42) vice-president and general manager of the chemical department.

The contract with the General Electric company is similar to that with the du Pont company in that the fee for all work to be performed is $1. The Government will retain control of the plant.

Electron Tube Converts Mechanical Motion Directly

Development of a tiny metal electron tube, the Vibroton, which converts mechanical motion directly into variable electron flow has been announced by the Radio Corporation of America laboratories at Princeton and Harrison, N. J. The tube weighs less than an ounce and is only about one inch in length and one quarter of an inch in diameter.

Though the new tube is not yet in production, the company will make a limited number available to manufacturers of electronic equipment who are interested in experimenting with it for use in future products. It is expected that the tube will find wide application in future designs of phonograph pickups. Other fields of application are in microphones and in industrial equipment where translation of mechanical motion to electron circuits is desirable for purposes of control or measurement.

The tube is a metal triode, at one end of which is an extremely thin flexible metal diaphragm through which external motion is transferred to a movable electrode within the tube. Leads for supplying voltages are brought out through the other end. The tube operates as an integral part of the pickup head and the radio phonograph amplifier without the need of a preamplifier or coupling transformer.

Life tests have shown the tube to withstand severe treatment over long periods and to be stable under temperature and humidity changes.

Veterans Administration Sponsors on-the-Job Training

In connection with efforts to publicize the on-the-job training phase of its rehabilitation program, the Veterans Administration reports that widespread interest in electrical work has developed among the Armed Forces.

Under the rehabilitation program the aptitudes and qualifications of all trainees are reviewed carefully by the Administration staff before they are approved for on-the-job training, so that the danger of misfits is reduced to a minimum.

Supplementary living-cost allowances can be arranged to cover a period of months or years suitable to the particular job training schedule. While details of any such program are of course subject to the approval of the Veterans Administration, it is said that arrangements are much more flexible for men in the rehabilitation program than outside it. Employers who are

interested can obtain full details by telephoning the nearest office of the Veterans Administration.

Eligible veterans are those who meet the four following requirements:

1. The person must have been in the active military or naval service on or after September 16, 1940, and prior to the termination of the present war.

2. He or she must be discharged or released from the active service under conditions other than dishonorable.

3. He or she must have a disability incurred in or aggravated by such service for which pension is payable under laws administered by the Veterans Administration, or would be but for the receipt of retirement pay.

4. He or she must be in need of vocational rehabilitation to overcome the handicap of such disability.

JOINT ACTIVITIES

UET Honors Louvain Rector With Luncheon in New York

Monsignor Honoré van Waeyenbergh, rector of Louvain University, Belgium, was guest of honor at a luncheon given by the United Engineering Trustees, Inc., at the University Club in New York on June 19.

Monsignor van Waeyenbergh, who is in the United States visiting American universities with the heads of three other Belgian universities, was introduced to the luncheon guests by John P. H. Perry, president of the UET and vice-president of the Turner Construction Company, New York. In his address, the rector discussed his university's present difficulties caused by a record enrollment combined with an almost total lack of facilities which were destroyed by the war.

AIEE Past President Harold S. Osborne (F '21) was among the luncheon guests.

OTHER SOCIETIES •

Professional Engineers Head Asks Support From Profession

"The public deserves the same protection in the engineering profession as it now has in the medical and legal professions," declared Paul H. Robbins in a statement on his recent appointment as executive director of the National Society of Professional Engineers.

Calling for support of the registration laws existing in 47 states and in the territories, Mr. Robbins said "These laws, however, must be implemented by a united effort on the part of all engineers to create in their own profession and among the public as well, a professional consciousness of the responsibilities entailed. The National Society of Professional Engineers, with its member state societies and its local chapters, is recognized and supported by thousands of engineers as the organization best equipped to accomplish this throughout the whole profession."

"The professional engineer," Mr. Robbins continued, "has two principal needs to maintain his professional standing. He must continue throughout his entire engineering career to keep abreast of technological developments in his chosen field and to be constantly alert to his professional, economic, and social responsibilities to society. To this latter need, the National Society of Professional Engineers is pledged. The society has grown since 1934 to a membership exceeding 12,000 members indicating that more and more engineers are recognizing the need for this unified approach from a national standpoint to the common problems of all engineers."

Mr. Robbins comes to his new appointment from three years as Director of Training and Employee Relations at the New York Port of Embarkation. He is a graduate in engineering from Syracuse University and Massachusetts Institute of Technology.

New Edition of ASTM Standards on Heating and Resistance Alloys

Issuance of a current edition of "ASTM Standards on Electrical Heating and Resistance Alloys" has been announced by the American Society for Testing Materials.

The publication comprises some 30 specifications and tests which include four tests for electrical resistance alloys, two specifications and three tests for electrical heating alloys, two proposed specifications and one proposed method of test for electric furnace alloys, one specification and twelve tests for materials for radio tubes and lamps, three tests for heat-resisting alloys, and two tests for thermostat metals.

Future Meetings of Other Societies

American Chemical Society. National Chemical Exposition, September 10–14, 1946, Chicago, Ill.

American Society of Mechanical Engineers. Fall meeting, September 30–October 2, 1946, Boston, Mass.

American Welding Society. Annual meeting, November 17–22, 1946, Atlantic City, N. J.

Illuminating Engineering Society. National convention, September 18–21, 1946, Quebec, Quebec, Canada.

Instrument Society of America. Exhibit and conference, September 16–20, 1946, Pittsburgh, Pa.

Iron and Steel Exposition. October 1–4, 1946, Cleveland, Ohio.

National Electrical Contractors Association. Annual meeting, October 14–18, 1946, Atlantic City, N. J.

National Electronics Conference. October 3–5, 1946, Chicago, Ill.

National Exposition of Power and Mechanical Engineering. December 2–7, 1946, New York, N. Y.

Refrigeration Equipment Manufacturers Association. Fourth refrigeration and air conditioning exposition, Cleveland, Ohio, October 29–November 1, 1946.

Television Broadcasters Association, Inc. Second conference and exhibition, New York, N. Y., October 10–11, 1946.

In addition a technical paper, "Calculation of Electrical Contacts Under Ideal Conditions," by E. I. Shobert II, is included.

Copies of the 184-page publication in heavy paper cover can be obtained from ASTM headquarters, 1916 Race Street, Philadelphia 3, Pa. Single copies are $2; orders for from 10 to 49 copies are filled at $1.50 per copy.

IES Announces New Officers. Newly elected officers who will be inducted at the society's annual convention in Quebec, Quebec, Canada, in September have been announced by the Illuminating Engineering Society. The officers are:

President—Gilbert K. Hardacre, manager of commercial sales, Public Service Company of Northern Illinois

General Secretary—Walter Sturrock

Treasurer—Charles H. Goddard

Vice-president—Lee E. Tayler

Directors—Allan Parker and P. M. Rutherford

EDUCATION • • •

Massachusetts Institute Appoints Dean of Engineering School

Appointment of Professor Thomas K. Sherwood as dean of the school of engineering at the Massachusetts Institute of Technology, Cambridge, recently was announced by President Karl T. Compton. Professor Sherwood has been deputy dean of engineering since February 1946 as well as professor of chemical engineering.

During the war Professor Sherwood was division member of the National Defense Research Committee with which he had been associated since 1940. In 1942 he was consultant to the Baruch Committee, and in 1944 he was appointed expert consultant to the war department. He became assistant professor of chemical engineering at Massachusetts Institute of Technology in 1930, and was appointed professor in 1941.

Hydrodynamic Fellowships at Stevens. Several fellowships for graduates of engineering colleges have been established by the Experimental Towing Tank Laboratory at Stevens Institute of Technology, Hoboken, N. J., it was announced recently by Doctor Kenneth S. M. Davidson, director of the Tank. The value of the fellowships, which are granted for one year, will be graded according to educational background and experience. While no regular graduate school courses are a requisite part of the fellowship, opportunity will be provided, when practicable, for a fellow to enroll in graduate courses at Stevens Institute or at some neighboring graduate school. Applications should be sent to Professor John P. Fife, director of personnel of the experimental towing tank.

LETTERS TO THE EDITOR

INSTITUTE members and subscribers are invited to contribute to these columns expressions of opinion dealing with published articles, technical papers, or other subjects of general professional interest. While endeavoring to publish as many letters as possible, Electrical Engineering reserves the right to publish them in whole or in part or to reject them entirely. Statements in letters are expressly understood to be made by the writers. Publication here in no wise constitutes endorsement or recognition by the AIEE. All letters submitted for publication should be typewritten, double-spaced, not carbon copies. Any illustrations should be submitted in duplicate, one copy an inked drawing without lettering, the other lettered. Captions should be supplied for all illustrations.

A New Type Dismountable Motor

To the Editor:

A modern electric motor of reputable make can be considered as very nearly a perfect machine when working under proper conditions, and involuntary stoppages and breakdowns are rare. Nevertheless such stoppages have not yet been wholly eliminated, one of the most serious results of which generally is the loss of production which occurs while the motor is being withdrawn, stripped down until the fault is discovered, and the damage made good. With the object of reducing to a minimum any such loss of time or production in the case of possible breakdown due to the driving motor, a Spanish firm of motor manufacturers, Bomba Prat S. A., Badalona, has designed and patented a new type of dismountable motor which now is being manufactured on a considerable scale in small sizes. Its design is such as to permit a ready withdrawal of any of its component parts, and another feature of its construction is the provision of special ball bearings by which 10,000 hours of service can be guaranteed without renewing the lubricant.

The design departs considerably from the normal construction in that the component parts form distinct groups, any one of which can be withdrawn and replaced by a substitute within a few minutes. For instance should trouble develop in the stator, this can be withdrawn and another substituted without having to dismount either rotor or bearings; or if any fault occurs in the rotor or bearings these likewise can be withdrawn without affecting either the stator or frame. This result has been achieved by the careful design of the main groups of essential elements which consist of

1. The shell or frame forming the main portion which is fixed to the seating and houses the other parts.

2. The fixed group consisting of the stator which is fixed to the frame in such a manner as to permit of its easy removal.

3. The rotating group comprising bearing assembly, shaft, pulley, and rotor, so arranged that by slackening off a couple of nuts it is possible to withdraw the whole without interfering with either the stator or the frame.

The stator is mounted in the frame by means of hooked bolts, and protection is afforded by means of a cover. The frame provides a seating for the stator, and ensures its correct location. The electric connections consist of suitable flexible leads projecting through a hole in the frame, but which can be pushed back readily when the stator has to be withdrawn.

The first and simplest step in dismounting is the removal of the cover, which is merely a press fit over the stator. The rotor can be removed from either side equally readily.

The design of the bearing housing is such that, once it is withdrawn from the machine, it also can be dismounted completely, all that is necessary being to remove the gland nut and the cover secured by the bolts, after which rotor and shaft can be withdrawn from the other end of the bearing housing, allowing the bearings to be dismounted. Fan blades are provided on the rotor which serve to force air round the stator and out through the opening.

In size the new design of dismountable motor is a trifle longer than one of the standard design, and the price for a given horsepower and speed is stated to be practically identical with the electric motors of standard construction built by the same firm.

A. J. GIBBS SMITH
(Solihull, Warkwickshire, England)

An Over-All Organization for the Engineering Profession

To the Editor:

I have read with considerable interest the report of the subcommittee of the AIEE planning and co-ordinating committee. The subject of a professional organization embracing engineers of all classes certainly has come to the forefront during the past five to ten years. This keen interest in the subject shows that engineers are recognizing the importance of an over-all engineering organization as a means of attaining that professional status to which they are entitled.

If we are to be professionals, rather than just hired men, it appears to me that the following items are necessary:

1. Certification of some sort, showing that the individual to whom it is issued has passed the minimum requirements set up by the legally constituted board created for that purpose.

2. An organization whose membership is composed of such members, regardless of the branch of engineering to which they may belong. Such an organization should be able to speak for the profession as a whole and not be dependent upon the wishes of any technical organization with aims which may not be the same as those of the majority of all engineers.

3. Rules of conduct to which each professional engineer might subscribe and which would tell the world what the individuals belonging to such an organization believe and how they expect to conduct themselves in their dealings with each other and with their fellow men.

4. Assurance to the public that high caliber individuals only will be permitted to belong. This will mean a policing of the profession by the members themselves, bringing violators of the code of ethics to trial and punishment in some manner, such as suspension or expulsion from the organization.

An over-all society would be in a much better position to do such policing of its membership, so that after a lapse of time the finger of suspicion would point to an engineer who did not belong to the organization. The public would ask, "What is the matter with him, why does he not belong?" If the profession does not keep its own house clean, someone on the outside will do it with results perhaps not to our own liking.

Such an over-all organization must be made up of individuals who believe in it and who do not have to operate through some technical society which may not be always in sympathy with the objects desired. The technical side usually contains a considerable number of members who are not "interested in engineering" and therefore do not have the same viewpoint as the engineer who takes the trouble to become registered.

Such an over-all organization will not detract from interest in a technical organization. Each professional engineer should be a member of at least two: one the overall society which has as its objective the raising of the standards of the profession and thereby improving the welfare of the engineer and the services he renders to his country; and the other, a technical society which seeks to improve the engineer's technical knowledge in his specialized activity.

The meetings of the first group should be devoted to subjects in which all engineers are interested, including the following:

1. Discussion of state and national labor laws a they pertain to the engineering profession.

2. Determination of proper and equitable fees for consulting and designing work.

3. Establishment of scales of wages and salaries for engineers having various responsibilities.

4. Policing of the profession and trial of members who violate the code of ethics.

5. Development of engineers in the humanistic subjects.

6. Study of effect of existing and proposed laws on the profession, and the encouragement of the passage of laws which will raise engineering standards.

7. Methods of assisting institutions of learning.

Such an organization would be a "grass roots" organization, one in which each member would have his interest aroused first as an engineer and member of the local unit to which he belongs, and second, as a member of the state organization, and third, as a member of the national. To try to form such an organization by means of a committee selected from any of the existing technical organizations would be a very difficult task, on account of the fact that each organization at the present time probably has its own suggestions as to what course of action should be taken, and for any such selected delegates to combine their viewpoints, so that they can present a

unified front would be extremely difficult.

Why waste time deciding upon what sort of an organization shall be created, when there already exists such an organization, namely, the National Society of Professional Engineers? This organization limits its membership to registered engineers with a few exceptions and is directly subject to the will of the membership through the state and district societies which are compouent parts of the national. If we are ever to achieve the goal which all of us hope is not too far away, let us stop discussing which kind of organization is better, and instead let all of us join the National Society of Profesional Engineers, a rapidly growing organization, that seems to fill the bill adequately.

R. R. HERRMANN (A '16, M '21)
(Manager rate and sales research, Northern States Power Company, Minneapolis, Minn.)

Electrical Essays for Recreation

To the Editor:

The following problem in electromagnetic induction may be of some interest in connection with the recent letters of Mr. Richter and Mr. Hansen in *Electrical Engineering*, (*Oct '45, p 387, and Feb '46, p 95*).

Consider a cylindrical iron tube, Figure 1, moving concentrically along a straight conductor carrying a steady current. On the inner and outer surfaces of this tube rest fixed brushes which are connected by stationary wires to a galvanometer or voltmeter. Will the measured electromotive force be independent of the permeability of the tube, or in other words will the electromotive force be identical for similar tubes of iron and brass?

The problem is interesting as an illustration of the correct method of applying two alternative theories of electromagnetic induction.

According to the Maxwell–Lorentz theory, in order to calculate the electromotive force induced in the closed circuit of Figure 1 we must consider two effects:

1. The motion of the iron tube through the total or resultant magnetic field, B, in its interior. This will result in a motional component of electromotive force proportional to Bv, or $B_0\mu v$, where B_0 is the magnetic field when $\mu = 1$, μ is the permeability of the iron, and v is the velocity of the tube.

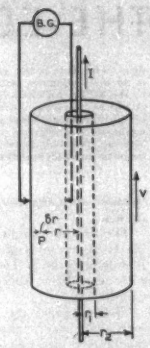
2. The rise of the magnetic field in the space through which the top of the tube travels, in a short time δt, as it moves into the voltmeter circuit will induce an electromotive force in the closed circuit equal to the rate at which the flux in this space increases. That is, it will result in a "transformer" component of electromotive force proportional to

$$B\left(1-\frac{1}{\mu}\right)v$$

in a direction opposite to the first component of electromotive force.

The electromotive force measured therefore will be proportional to $B_0 v$, and will be independent of the permeability of the moving tube.

Figure 1



By the moving-field theory, however, the tube is to be taken as moving through B_0, the stationary field of the stationary axial wire, only, and the field $B_1 = (\mu - 1)B_0$ of the iron atoms is to be taken as moving with the tube. On account of the symmetry the field B_1 is confined to the interior of the tube, and hence cannot induce any electromotive force in the stationary leads. Further, since no currents are changing in the primary circuit, there is no "transformer" component of electromotive force. Hence the measured electromotive force immediately is seen to be proportional to $B_0 v$.

Now let an observer who travels with the tube calculate the electromotive force by each theory in turn. If he uses the Maxwell–Lorentz theory, he takes the magnetic field of the conductor as stationary relative to himself, and he finds the electromotive force to be due to the motion of brushes, leads, and voltmeter, through this field. In other words, the physical phenomena, though leading to the same result, appear totally different to the two observers.

On the other hand, if the moving observer applies the moving-field theory, he accepts the motion of the field B_0 relative to himself, and finds the electromotive force to be induced in the tube by this moving field. Thus the moving-field theory, as applied by different observers, gives a definite and unambiguous answer as to the seat of the induced electromotive force; the Maxwell–Lorentz theory, however, is ambiguous, for the seat of the electromotive force depends upon the motion of the particular observer who applies the theory.

On page 315, volume 85 (1939) of the *Journal* of the Institution of Electrical Engineers will be found a more complete statement of these theories and an account of an experiment which I performed which showed conclusively that the induced electromotive force is independent of the permeability of the cylinder. Its interest to Mr. Richter and Mr. Hansen appears to lie in the fact that application of the flux-linking or flux-cutting laws alone will, in the conventional Maxwell–Lorentz theory, yield an incorrect result. Further, in using the moving-field theory, the various components of the magnetic field must be distinguished: only those components due to moving circuits or magnets should be taken as moving.

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NEW BOOKS . . .

The following new books are among those recently received at the Engineering Societies Library. Unless otherwise specified, books listed have been presented by the publishers. The Institute assumes no responsibility for statements made in the following summaries, information for which is taken from the prefaces of the books in question.

INDUSTRIAL ELECTRIC LAMPS AND LIGHTING. By E. S. Lincoln. Essential Books, New York, N. Y., 1945. 342 pages, illustrated, 8¾ by 5½ inches, cloth, $3. All types of industrial lamps are covered with detailed instructions for their use with proper reflectors for indoor and outdoor lighting. A large amount of practical data is presented in the form of tables and charts. In addition to the commonly used light sources, space is devoted to emergency lighting and equipment, bactericidal lamps, black light, and fluorescent materials.

SMOKE PREVENTION ASSOCIATION OF AMERICA. Conference on Smoke Abatement and Conservation of Fuels, *Proceedings*, Columbus, Ohio, 1945. Smoke Prevention Association, City Hall Square Building, Chicago, Ill., mimeographed, 105 pages, illustrated, 11 by 8½ inches, paper, $2. Fifteen papers are presented covering a variety of topics. The larger aspects of smoke abatement and fuel conservation are considered in the first group. Succeeding papers deal with such specialized fields as dust collection, the relation between meteorology and smoke abatement, the design of locomotive equipment, coal analysis, and incineration problems. An outline is submitted as a suggested approach to participation of the Weather Bureau in air pollution research.

PAMPHLETS . . .

The following recently issued pamphlets may be of interest to readers of "Electrical Engineering." All inquiries should be addressed to the issuers.

The Story of the 1946 (National Electrical) Code Changes. Anaconda Wire and Cable Company, 25 Broadway, New York 4, N. Y., 15 pages, no charge.

Industrial Research Progress at Armour Research Foundation of Illinois Institute of Technology, 1944–45. Armour Research Foundation, Chicago 16, Ill., 20 pages, no charge.

Axonmetric Drawing. By Paul F. Boehm. John R. Cassell Company, Inc., 110 West 42d Street, New York 18, N. Y., 18 pages, no charge.

Setting Up an Appreaticeship Program. Apprentice-Training Service, United States Department of Labor, Washington 25, D. C., 30 pages.

TRANSACTIONS SECTION

Reprint of Corresponding Pages From the Current Annual AIEE Transactions Volume

The Influence of the Concentration and Mobility of Ions on Dielectric Loss of Insulating Oils

BUN PO KANG
ASSOCIATE AIEE

Synopsis: The causes of dielectric loss in insulating oils and the means to reduce it to a minimum have always been important in high voltage engineering. In this study the relationships between the amount of impurities, which furnish a source of free ions in an oil, and the viscosity, which influences the mobility of the ions, on the one hand and the dielectric loss on the other are investigated. The results present some definite relationships between them and point out that in two oils of the same "electrical purity," the one with higher viscosity will have lower dielectric loss.

SINCE DIELECTRIC LOSS is a matter of primary importance in high voltage insulation, many phases of the phenomenon have been a subject of frequent discussion among high voltage engineers. In liquid dielectrics, such as mineral oils which are used extensively for transformer and cable insulations and for many other purposes, the loss has been found to be caused largely by ionic conduction.[1,2] In a few cases, dielectric absorption caused by molecular polarization has been found to be present also.[1] However, polarization in oils resulting in an absorptive component of dielectric loss seldom appears significant.

In the study of the nature of and the mechanism that causes dielectric loss in oil, where the loss is due to ionic conduction alone, there are two important factors which merit investigation. In order to have ionic conduction, the oil must possess ions, and the ions must be free to move. If the ion content of an oil is constant, the dielectric loss should vary inversely as the viscosity. It has been found that within a limited rage of temperature, this relation holds true, and the product of the conductivity and the viscosity of the oil is approximately a constant. This product has been suggested as a measure of the free ion content, which has also been termed the "electrical purity" of the liquid.[3]

Under constant electric stress, the dielectric loss for liquids without significant dielectric absorption is proportional to the conductivity of the liquid.

$$W = \frac{\lambda A E^2}{L} \qquad (1)$$

where

A is the area of electrode in square centimeters
L is the electrode separation in centimeters
E is the applied potential in volts
λ is the conductivity in mhos per centimeter
W is the dielectric loss in watts

Since in the cases of ionic conduction the conductivity should be directly proportional to the ion content, it follows that the ion content also should be proportional to the product of the viscosity and the dielectric loss. However, this is not always borne out by experiment except within a very small range of temperature. If the range of temperature be extended, the ion content is found to increase with temperature. Apparently this is caused by thermo-agitation, which in turn causes further ionic dissociation and the generation of new ions within the oil.[4]

For the same degree of purification, the dielectric loss is invariably lower in an oil of higher viscosity. Even though the amount of impurity and the number of ions present in two different oils may be identical, the mobility of the ions is much greater in the oil of lower viscosity and consequently the conduction current is higher.

Since it is not only interesting but useful to know the relationships between the concentration and mobility of the ions of an insulating oil on the one hand and dielectric loss on the other, it is the purpose of this work to establish a correlation between them.

The Experiment

Three original oils, designated as oil sample 1, oil sample 6, and oil sample 7, were used. Samples 1 and 7 were highly refined oils furnished by well-known refineries, sample 1 being of low viscosity and sample 7 being of high viscosity. Sample 6 was an oil known to be highly susceptible to oxidation and was subjected to severe oxidation at 150 degrees centigrade under atmospheric condition for seven days. Oil samples 2 to 5 were mixtures of samples 1 and 6 (by weight) at 10, 25, 50, and 75 per cent, respectively, of oil 6. Oil samples 8 to 11 were mixtures of oils 7 and 6 in similar percentages.

For the measurements of viscosity and dielectric loss, these samples were classified into two groups. Group A, oil samples 1 to 6, consisted of the low viscosity samples, and group B, oil samples 7 to 12, consisted of the high viscosity samples. Samples 6 and 12 were the same oil.

Viscosity measurements were made with a standard Saybolt viscosimeter. The 60-cycle power factor measurements were made with an Atkinson bridge.[5] The samples were measured in a nickel cell with an electrode area of 40.742 square centimeters and a distance of separation of 1.27 millimeters at a voltage stress of 197 volts per millimeter. The values of dielectric loss given on the following figures are the total loss of each specimen under test. If the loss per centimeter cube is desired, these values

Paper 46-110, recommended by the AIEE committee on basic sciences for presentation at the AIEE summer convention, Detroit, Mich., June 24-28, 1946. Manuscript submitted June 27, 1945; made available for printing May 1, 1946.

BUN PO KANG is a research engineer with the plastics department of the E. I. du Pont de Nemours and Company and an electrical engineer on leave of absence from the Yungli Chemical Industries, Ltd., China. This paper was written when he was a post-doctoral scholar at Johns Hopkins University and concurrently an engineer with the high tension laboratories of the General Cable Corporation. He wishes to acknowledge his appreciation to Professor J. B. Whitehead and Mr. R. W. Atkinson for their interest and advice concerning this work, and the General Cable Corporation for the use of its facilities.

Table I. Viscosities of the Oil Samples at Different Temperatures

Sample	40 C	60 C	80 C	100 C	120 C	150 C
1	—	0.086	0.05	0.031	0.02	—
2	0.21	0.10	0.055	0.035	0.021	—
3	0.305	0.13	0.073	0.046	0.03	—
4	0.65	0.23	0.115	0.065	0.04	—
5	1.60	0.53	0.205	0.10	0.06	—
6	4.90	1.10	0.40	0.17	0.094	0.048
7	8.00	1.40	0.54	0.24	0.14	0.074
8	—	1.40	0.54	0.24	0.135	0.069
9	—	1.35	0.505	0.23	0.13	0.066
10	—	1.35	0.455	0.201	0.105	0.06
11	—	1.20	0.43	0.19	0.10	0.059
12	4.90	1.10	0.40	0.17	0.094	0.048

The values of viscosity given are in poises.

Table II. Power Factor and Dielectric Loss of Oil Samples in Group *A*

Sample		40 C	60 C	80 C	100 C	120 C	150 C
1	Capacitance	—	66.7	66.1	65.7	65.0	—
1	Power factor	—	0.18	0.41	0.61	1.56	—
1	Dielectric loss	—	2.9	6.3	12.6	23.9	—
2	Capacitance	67.7	67.2	66.7	66.0	65.5	—
2	Power factor	0.35	1.59	4.39	10.20	18.35	—
2	Dielectric loss	8.82	25.2	69.3	167.5	283.0	—
3	Capacitance	68.6	67.9	67.5	66.7	66.0	—
3	Power factor	0.82	2.38	7.10	17.2	33.8	—
3	Dielectric loss	13.2	41.5	113.0	272.0	530.0	—
4	Capacitance	69.4	68.8	68.5	67.6	67.2	—
4	Power factor	0.75	2.72	7.85	20.1	36.3	—
4	Dielectric loss	11.95	44.1	127.5	322.0	575.0	—
5	Capacitance	70.7	70.0	69.4	69.0	68.5	—
5	Power factor	0.36	1.85	6.52	19.7	39.9	—
5	Dielectric loss	5.97	30.2	107.0	322.0	642.0	—
6	Capacitance	71.8	71.0	70.5	69.5	68.8	68.1
6	Power factor	0.19	0.98	4.55	15.7	42.5	89.8
6	Dielectric loss	3.75	16.4	75.6	358.0	693.0	1450.0

Capacitance is given in micromicrofarads, power factor in per cents, and dielectric loss in microwatts.

must be multiplied by a factor of 0.00312, which is the ratio of L/A, where L is the distance of separation and A is the effective area. The voltage stress was kept low to utilize the linear portion of the well-known current-voltage relation curve. For group A, the low viscosity oils, readings were taken at 40, 60, 80, 100, and 120 degrees centigrade for each sample, and for group B, the high viscosity group, readings were taken at 60, 80, 100, 120, and 150 degrees centigrade.

Experimental Results

The specific gravity temperature relations of the three original oil samples are given in Figure 1. The specific gravity of each of the mixtures at various temperatures can be computed easily from these curves by the use of the following relations:

$$\rho_2 = \frac{\rho_1\rho_3(W_1+W_3)}{\rho_1 W_3 + \rho_3 W_1} \qquad (2)$$

where

ρ_1, ρ_3 represent the specific gravities of the components

ρ_2 represents the specific gravities of their mixture

W_1, W_3 represent the weights of the components

After converting the viscosity readings at different temperatures for each sample from Saybolt seconds into poises, the results were given in Table I. To follow the more customary way of representing relationships of this kind, the logarithm of viscosity was plotted against the reciprocal of the absolute temperature in Figures 2 and 3. It is quite obvious that the relationship is essentially logarithmic. However, none of the curves is exactly a straight line but only very near to one.

The values of power factor and dielectric loss for each mixture at different temperatures are given in Table II for group A, and Table III for group B. Figure 4 gives the relations of the logarithm of dielectric loss as a function of the reciprocal of absolute temperature. Several of these curves are essentially straight lines and others are quite near to straight lines within limited range of temperatures. These relations may be expressed as

$$W = A - \frac{B}{T} \qquad (3)$$

where

W is dielectric loss in microwatts
T is temperature in degrees Kelvin
A and B are constants

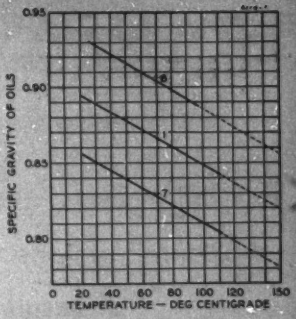

Figure 1. The variation of specific gravity with temperature of the original oil samples

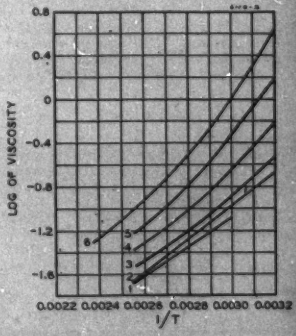

Figure 2. The viscosity–temperature characteristics of the oil samples in group A, η being viscosities in poises, T being temperatures in degrees Kelvin, and numbers designating the oil samples

which are similar to the expression used by Fuoss for the relation between conductivity and temperature.[6]

Dielectric Loss and Viscosity Relation

Based on the curves of Figures 2, 3, and 4, a relationship between viscosity and dielectric loss of each sample can be established. Figure 5 presents clear evidence that the relation is logarithmic,

$$\log W = A - B \log \eta \qquad (4)$$

The curves are approximately straight lines within reasonable allowance for experimental error, and each group of samples appears to have a constant slope of its own. These results confirm the prediction of other workers in this field.[4]

Discussion

Since the dielectric loss of sample 6 is much higher than that of samples 1 and 7 (from 6 to 30 times under similar conditions), the ions present in the various mixed samples may be assumed as coming from sample 6. If there were no other causes for further dissociation in the oil, the dielectric loss of each sample should be a linear function of the percentage of deteriorated oil added. Figure 6 shows dielectric loss as a function of percentage of deteriorated oil added at different constant temperatures. The curves of group *A* for temperatures below 100 degrees centigrade show an increase of dielectric loss with the percentage of deteriorated oil added, but only up to a certain point, and beyond this point the losses decrease again. The ascending portion of each curve is caused by the increase of ion content of the specimen by adding a larger quantity of deteriorated oil. Since the deteriorated oil, sample 6, has much higher viscosity than sample 1, upon addition of sample 6, the viscosity of the mixture increases rapidly. Even though the ion content continues to increase, the mobility of these ions is greatly reduced by the increase in viscosity. After reaching a certain point, the viscosity becomes so high that even though the ion content continues to increase, the mobility of the ions diminishes rapidly and the dielectric loss decreases again.

Based on these curves, if one assumes that the ion content N is equal to the product of viscosity η and dielectric loss W, mathematical analysis shows that in Figure 6 all curves in group *A* should pass through a maximum, but not the curves in group *B*. This is found to be true. However, because of the fact that sludges and other solid impurities might have been formed in oil 6 because of oxidation, the viscosities of the mixtures did not follow exactly the relation usually used for computing the viscosity of mixtures of nonpolar liquids.

$$\frac{1}{\eta_2} = \frac{X}{\eta_1} + \frac{1-X}{\eta_2} \tag{5}$$

where

η_1, η_2, η_3 are viscosities of the components and the mixture

X is the percentage of the liquid with viscosity η_1

The theoretical values are lower in comparison with experimental data. Based on theoretical considerations, one can show that the maximums of dielectric loss occur when

$$X = \frac{\eta_1}{2(\eta_1 - \eta_2)} \tag{6}$$

provided η_1 is not equal to η_2. The experimental values deviated from this prediction somewhat because of the high viscosities obtained. However, the general shapes of the curves support very well the assumption that

$$W = \frac{N}{\eta} \tag{7}$$

In group *B*, both samples 6 and 7 have approximately the same viscosity; in fact, the viscosity of sample 6 is a little lower than the viscosity of sample 7, and consequently the increase of the percentage of deteriorated oil increases both the concentration and mobility of the ions, and the conduction current and dielectric loss also are increased.

In a limited range of temperature within which new ions are not generated by thermo-agitation in the oil, the dielectric loss should be proportional to the percentage of deteriorated oil added if the viscosity of the mixture is kept constant. This is found to be true for samples of higher viscosities according to Figure 7, curves *B* and *C*. In this group the viscosities of the two components were only slightly different, and the temperature differences were small when the samples were brought to the same viscosity. Consequently, thermal effects may be considered negligible.

If the viscosities of the two components

Table III. Power Factor and Dielectric Loss of Oil Samples in Group *B*

Sample		60 C	80 C	100 C	120 C	150 C
7	Capacitance	64.0	63.2	63.8	62.4	61.1
7	Power factor	0.062	0.25	0.59	1.25	3.96
7	Dielectric loss	0.945	3.78	8.82	18.9	57.3
6	Capacitance	64.5	64.0	63.2	62.8	61.8
8	Power factor	0.25	0.58	1.51	3.05	9.0
8	Dielectric loss	3.78	8.82	22.7	45.3	132.48
9	Capacitance	65.5	65.2	64.5	63.8	63.0
9	Power factor	0.31	1.11	3.05	6.7	14.8
9	Dielectric loss	4.73	17.0	46.7	101.0	220.0
10	Capacitance	67.5	66.8	66.3	66.0	64.5
10	Power factor	0.56	1.99	6.01	13.3	25.5
10	Dielectric loss	8.82	31.5	94.5	208.0	392.0
11	Capacitance	69.3	68.6	67.9	67.2	67.1
11	Power factor	0.81	3.42	11.0	24.2	47.6
11	Dielectric loss	13.25	55.5	177.0	385.0	756.0
12	Capacitance	71.0	70.5	69.5	68.8	68.1
12	Power factor	0.98	4.55	15.7	42.5	89.8
12	Dielectric loss	16.4	75.6	258.0	693.0	1450.0

Capacitance is given in micromicrofarads, power factor in per cent, and dielectric loss in microwatts.

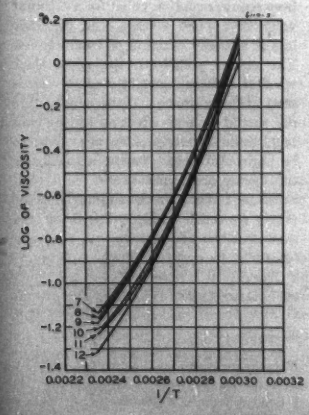

Figure 3. The viscosity–temperature characteristics of the oil samples in group *B*, η being viscosities in poises, *T* being temperatures in degrees Kelvin, and numbers designating the oil samples

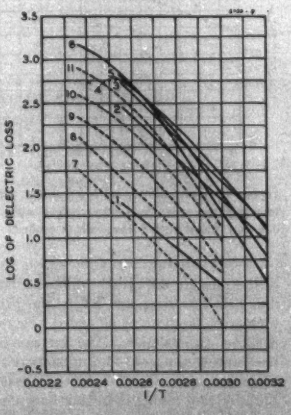

Figure 4. The variation of dielectric loss with temperature, loss being given in microwatts, temperature in degrees Kelvin, solid lines for oils in group *A*, and dotted lines for oils in group *B*

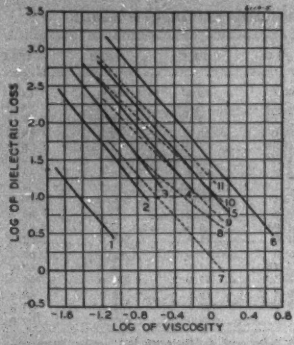

Figure 5. The variation of dielectric loss with viscosity, loss being given in microwatts and viscosity in poises

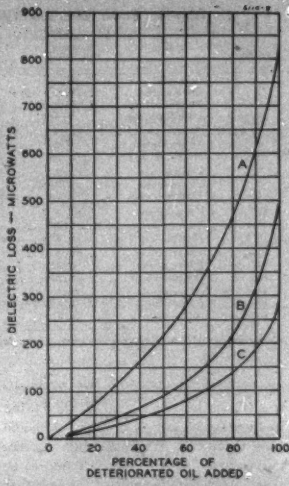

Figure 8. The influence of deteriorated oil on dielectric loss at constant viscosity for low viscosity mixtures

Curve *A* at 0.08 poise, curve *B* at 0.15 poise, and curve *C* at 0.2 poise

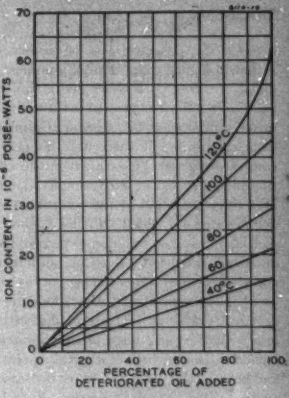

Figure 10. The influence of deteriorated oil on ion content at constant temperature for low viscosity mixtures

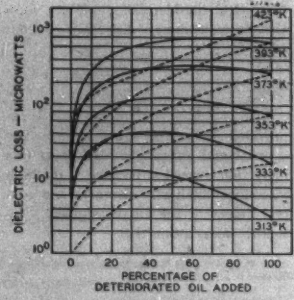

Figure 6. The variation of dielectric loss with percentage of deteriorated oil added at various temperatures, solid lines representing oils in group *A* and dotted lines, oils in group *B*

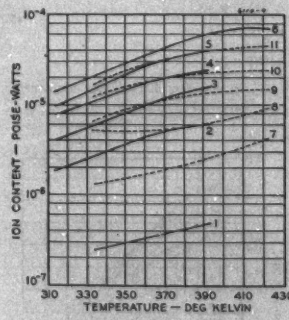

Figure 9. The variation of ion content with temperature, solid lines representing oils in group *A* and dotted lines, oils in group *B*

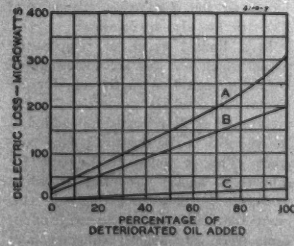

Figure 7. The influence of deteriorated oil on dielectric loss at constant viscosity for high viscosity mixtures

Curve *A* at 0.15 poise, curve *B* at 0.2 poise, and curve *C* at 1.0 poise

of the mixture are greatly different, the dielectric loss does not follow the percentage of deteriorated oil added. Figure 8 shows this relation. The increase in temperature required to bring the heavier oil to the same viscosity causes thermoagitation and results in furthur ionic dissociation in the oil, principally from the impurity content, which accounts for the unusually rapid rise of dielectric loss at the higher percentages of the added deteriorated oil.[7]

In order to substantiate the assumption that temperature increase will increase the concentration of ions in the oil, two sets of curves are plotted in Figure 9, using ion content as a function of temperature for each mixture. The values of ion content for different samples are taken as that which was suggested by Whitehead, namely, the product of conductivity and viscosity.[8] For want of a suitable unit to express ion content, these values are expressed in poise-watts. In these particular cases, dielectric loss is used instead of conductivity. As it has been seen in equation 1 that for a constant value of applied voltage, the dielectric loss is a linear function of conductivity. The curves will have the same slope whether dielectric loss or conductivity is used as the ordinate. If the temperature rise should have no effect on the ion content, these two sets of curves ought to be horizontal lines. In the actual cases the curves are found to rise with temperature, having almost similar constant slopes for each group. Based on the average slope of these curves, the relations may be expressed in the equation

$$\log \frac{N_2}{N_1} = 0.008T \qquad (8)$$

where

N_1 is the ion content at temperature 1
N_2 is the ion content at temperature 2
T is the difference in temperature in degrees Kelvin

In a more general form, this expression may be written as

$$N_2 = N_1 e^{cT}$$

A New Electronic Timing Relay for Reducing Outages on Power Circuits

FRANK S. DLOUHY
ASSOCIATE AIEE

Synopsis: This paper describes a new timing relay for controlling relaying time on automatically reclosed circuit breakers on which inverse-time overcurrent relays are supplemented by instantaneous overcurrent relays. This device incorporates the advantages of instantaneous circuit breaker opening on the first, and in some cases the second, tripout to clear transient faults, and inverse-time opening on subsequent tripouts to obtain co-ordination with branch or sectionalizing fuses. It was designed for universal application on feeder circuits of the Oklahoma Gas and Electric Company system. Certain features which provide for optimum service reliability were incorporated in the design.

EVEN THOUGH all possible protective measures of prevention have been taken in the design of overhead circuits, faults, the majority of which are transitory in nature, still will occur. In order to minimize damage to equipment and interruption to service, the faulted section must be isolated promptly from the rest of the system. Experience has shown that transmission and distribution circuits, on which fault duration is limited to a maximum of 0.2 second, will seldom be out of service for long periods of time as a result of damaged insulators or burned conductors at the point of fault, except in peculiar cases of rare occurrence. Thus, the speed with which protective relays and circuit breakers operate to clear abnormal conditions has a direct bearing on service reliability.

The practice of instantaneous tripping of the source breaker for a fault at any point on the circuit is, by definition, a protective measure of amputation. But, when supplemented by rapid automatic reclosing, its effect on the ultimate load entitles it to be classified as a protective measure of mitigation. It limits the occurrence of permanent faults which are initiated by transient disturbances. In addition, it restricts branch or sectionalizing fuse operation, where possible, to faults of a permanent nature, and thereby reduces long outages on branches or sections of the circuit. Consequently, the realization of the advantages of instantaneous tripping supplemented by immediate initial reclosure has furnished an incentive for designing many ingenuous relaying schemes.

Probably the most effective and certainly the most economical method of securing high-speed relaying on circuit breakers serving multibranch fused circuits is that of superimposing controlled instantaneous overcurrent relays on inverse-time overcurrent relays, and utilizing immediate initial reclosure. This applies to the ground relay as well as the phase relays on grounded neutral circuits. The instantaneous relays are set, where possible, to initiate circuit breaker clearing of faults at any point on the circuit. When these relays are utilized for the second as well as the initial tripout, inrush magnetizing current transients following the initial reclosure may place a minimum limit on the pickup setting.

The co-ordination desired from this type of protective scheme is protection to the entire circuit during the first, and in some cases the second, tripout, in order to give temporary faults, such as flashovers resulting from lightning or momentary conductor contacts, an opportunity to clear before permanent damage occurs and before a branch or section is interrupted by fuse operation. Thus, in the case of faults which are cleared on the initial tripout, a momentary service interruption is substituted for a long outage from damaged equipment or blown fuses. In effect, this momentary service interruption is no more adverse than the voltage

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This gives further substantiation that the ion content is a function of temperature.

Following this indication, it suggests that if temperature should be kept constant, the value of ion content would be a definite function of the percentage of deteriorated oil added. Curves plotted using ion content as a function of percentage of deteriorated oil added at each temperature are shown in Figure 10. These curves show definitely that the ion content is a linear function of the percentage of deteriorated oil added when temperature is reduced to a constant.

Conclusion

This study shows that

1. Provided there is no dipole loss, the relationship between the dielectric loss W and viscosity η of an insulating oil may be expressed as

$$\log W = A - B \log \eta$$

which points out that the mobility of ions is an important factor in dielectric loss of an insulating oil.

2. Thermo-agitation, which causes further dissociation of the oil, increases dielectric loss by increasing the number of ions present.

3. Dielectric loss is increased rapidly by the addition of deteriorated oil. This bears out that dielectric loss is a function of the concentration or content of free ions in the oil.

4. An increase in concentration of ions in an oil may result in an actual decrease in dielectric loss if the viscosity is increased to the point where the mobility of the ions is decreased relatively more than the ion concentration is increased.

5. If nonpolar oils of the same degree of "electrical purity" are used for the low frequency or 60-cycle applications where the flow of the liquid is not important, it is seen that an oil of higher viscosity is preferable from the standpoint of lower dielectric loss.

References

1. THE CONDUCTIVITY OF INSULATING OILS—II, J. B. Whitehead. AIEE TRANSACTIONS, volume 50, 1931, pages 692–8.

2. THE CONDUCTIVITY OF INSULATING OILS UNDER ALTERNATING CURRENT STRESS, J. B. Whitehead, B. P. Kang. *Journal of Applied Physics*, volume 11, September 1940, pages 596–603.

3. THE DIELECTRIC LOSSES IN IMPREGNATED PAPER, J. B. Whitehead. AIEE TRANSACTIONS, volume 52, 1933, pages 667–81.

4. LIQUID DIELECTRICS (book), A. Gemant. John Wiley and Sons, New York, N. Y. Pages 67–8.

5. HIGH TENSION BRIDGE FOR MEASUREMENT OF DIELECTRIC LOSS IN CABLES, R. W. Atkinson. *The Electric Journal*, February 1925, page 58.

6. ELECTRICAL PROPERTIES OF POLYVINYL CHLORIDE-DIPHENYL SYSTEM, R. M. Fuoss. *Journal of American Chemical Society*, volume 63, February 1944, page 382.

7. LIQUID DIELECTRICS (book), A. Gemant. John Wiley and Sons, New York, N. Y. Page 69.

8. IMPREGNATED PAPER INSULATION (book), John Wiley and Sons, New York, N. Y. Page 57.

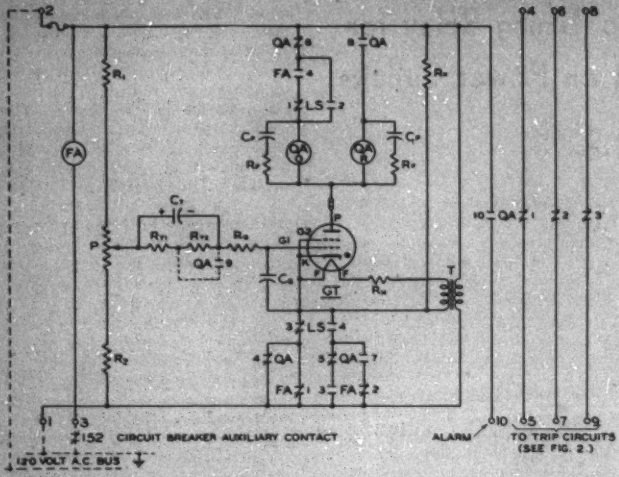

Figure 1. Schematic diagram of the electronic timing relay assembly

disturbance created by a longer clearing time of a fuse. When instantaneous relay protection is also utilized on the second tripout, the time interval between the initial and the second reclosure should be made as short as the imposed circuit breaker duty will permit in order to minimize outage time. Thus, in the case of transient faults which are not cleared initially but disappear on the second tripout, a 30- to 60-second service interruption is substituted for a probable long outage on some portion of the circuit.

To provide backup protection and selectivity between the circuit breaker and the branch or sectionalizing fuses in the event of a permanent fault, the instantaneousrelays must be removed from service prior to the initial, or in some cases the second, reclosure, and the inverse-time relays depended upon for subsequent tripping. Through time–magnitude coordination, the inverse-time relays will permit branch or sectionalizing fuses to clear the faulted section before initiating breaker operation for backup protection. Where sufficient co-ordination can be realized, these relays are seldom called upon to clear a fault.

Also, in the event of punctured insulators or lightning arresters, the prolonged arcing time secured on the inverse-time relays may produce additional damage and perhaps shatter the faulty equipment. This will permit the fault to be more easily located by patrolmen.

Once removed from service, the instantaneous relays should be held inoperative for a definite time after a reclosure as assurance that the fault was not permanent; otherwise, in the absence of selectivity a lockout of the circuit breaker will occur, resulting in a needless long outage on the entire circuit. To accomplish this, a preset time delay must be interposed between each reclosure and reestablishment of the instantaneous relays. This reset timing is as important in preventing long outages as the instantaneous relays themselves. It should be the minimum time necessary to determine a successful reclosure in order to provide instantaneous relay protection against the contingency of rapidly recurring transient faults.

It is apparent from the foregoing that an auxiliary device capable of the following functions is required:

It must remove the instantaneous relays from service prior to the initial, and in some cases the second, reclosure.

It must hold them inoperative until a successful reclosure is assured and then reinstate them to re-establish initial conditions for future disturbances.

Description of the Timing Relay

In view of the fact that a device fulfilling the foregoing requirements was not available and that existing methods of changing relaying time have certain undesirable features, an electronic timing relay was designed for universal application with relaying schemes utilizing instantaneous and inverse-time overcurrent relays. Briefly, it consists of an assembly of two telephone type relays, a thyratron timing tube, and associated electronic control components mounted in a small drawout case. Figure 1 is a schematic diagram of the assembly in which:

Thyratron *GT* is a gas tetrode, similar to type 2050, operated as a negative control tube. Its operation is discussed under "Theory of the Timing Circuit."

Relay *QA* is a telephone type electric-interlocking relay. It consists of two quick-acting relays mounted as a unit with their armatures mechanically interlocked. When lockup relay *QA-O* is energized, its armature latches and holds its contacts in the operated position until the release relay *QA-R* is energized to trip the latch. The release relay *QA-R* does not latch, but drops out when it is de-energized. Since these relays are pulse operated through their own contacts, a filter consisting of capacitor C_F in series with resistor R_F is shunted across each coil to assure positive operation.

Relay *FA* is a telephone type a-c relay operated as an equivalent circuit breaker auxiliary switch. Its unoperated position corresponds to the closed position of the circuit breaker.

Lever Switch *LS* is a double-pole double-throw selector switch which provides the selection of either one or two instantaneous relay operations.

Transformer *T* is a voltage dropping transformer for supplying the heater of the thyratron.

Other components: Resistors R_H and R_G are merely current limiting resistors. Capacitor C_G provides protection against high voltage transients. The functions of the other components are discussed with reference to Figure 3 under "Theory of the Timing Circuit."

To avoid confusion, the graphical symbols used in all the diagrams are, insofar

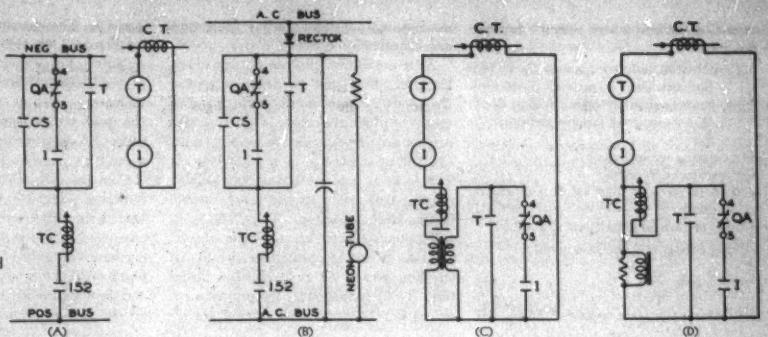

Figure 2. Location of electronic timing relay contacts in breaker tripping circuits

I—Instantaneous overcurrent relay
T—Inverse-time overcurrent relay
QA—Electronic timing relay (Figure 1)

A—D-c method
B—Capacitor method
C—Transformer method
D—Reactor method

as possible, those recommended by American Standards Association. Device contacts are shown for the de-energized or unoperated position of the device. All tube voltages are referred to the equipotential cathode. Instantaneous values of varying electrical quantities are represented by lower case letters, and their peak values by capital letters. Where possible, subscripts are chosen so as to be indicative of that portion of the circuit to which they apply.

Theory of the Timing Circuit

The basis of the timing relay design is the electronic timing circuit shown schematically in Figure 3, in which timing action is obtained by grid amplitude bias of the gas tetrode *GT*, acting as an inertialess circuit closing or opening device in series with relay *QA*.

An alternating voltage e_L of commercial frequency is impressed between *L1* and *L2*, and the tube heater circuit is energized from a filament transformer (not shown). The fixed resistors R_1 and R_2 in series with potentiometer *P* form a voltage divider circuit for controlling the potential applied to the control grid *G1*. With switch *S1* open and switch *S2* closed, unidirectional pulsating electron current flows from the cathode *K* to the grid *G1* during the half cycles in which *L1* and the grid are positive with respect to *L2* and the cathode. As a result of this rectification, a charge of the indicated polarity will accumulate in the timing capacitor C_T and which will be maintained as long as switch *S1* is open. Also, with switch *S1* open, the cathode *K* is connected through resistor R_K to line *L2* and is approximately at the same potential as the anode *P*; consequently, no electron current flows from cathode to the anode to energize the relay even though switch *S2* is closed.

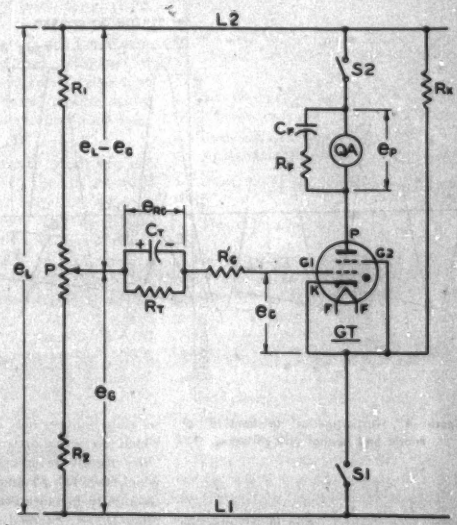

Figure 3. Schematic diagram of the electronic timing circuit

When switch *S1* is closed, the cathode is connected directly to line *L1* which impresses voltage e_L across the anode-cathode circuit and superimposes an alternating voltage e_G (in phase with the anode voltage) on the negative grid bias voltage E_{RC} of the timing capacitor C_T. The alternating component e_G of the grid bias voltage e_c tends to drive the grid positive at the same time the anode is positive; however, the tube does not conduct between cathode and anode until the grid bias voltage e_c is equal to or more positive than the critical ionization value determined from the tube's control characteristic.

The instantaneous relationship of the anode and control-grid voltages is shown graphically in Figure 4, in which time is reckoned from the instant switch *S1* is closed, and the alternating voltages are zero and increasing in the positive direction. It is apparent from this graphical representation that the magnitude of the grid bias voltage is a time function of both the unidirectional component e_{RC} and the alternating component e_G and defined by the equation

$$e_C = e_{RC} + e_G \qquad (1)$$

in which

$$e_{RC} = E_{RC} e^{\frac{-t}{R_T C_T}} \qquad (2)$$

is the solution of the differential equation defining the time-voltage characteristic of

capacitor C_T discharging through resistor R_T, where

E_{RC} = potential difference across C_T at the time discharge is initiated ($t=0$) and is approximately equal to $E_L - E_G$ if $R_G + R_K$ is small in comparison with R_T

C_T = capacitance in farads

R_T = resistance in ohms

t = time in seconds from initiation of discharge

ϵ = base of natural logarithms (2.718 . . .)

Solving equation 2 for time gives

$$t = R_T C_T \log_\epsilon \frac{E_{RC}}{\epsilon_{RC}} \qquad (3)$$

from which the time required for E_{RC} to decay to a desired value of ϵ_{RC} may be calculated.

Since the values of the timing capacitor C_T and discharging resistor R_T are fixed, the time constant is fixed and the time range is determined by the setting of the potentiometer P and the relative values of the components in the voltage divider circuit. The upper end of the potentiometer determines the minimum peak voltage to which the timing capacitor charges before initiation, the maximum peak voltage of the grid bias component after initiation, and therefore the minimum time delay between initiation and energization of relay. Conversely, the lower end of the potentiometer determines the maximum peak voltage to which the timing capacitor charges before initiation, the minimum peak voltage of the grid bias component after initiation, and thus the maximum time delay between initiation and energization of relay.

After expiration of a preset time delay, the tube "fires" and conducts current in the anode–cathode circuit during the half cycles in which the anode is positive with respect to the cathode, energizing relay QA and charging the filter capacitor C_F. The relay is held in during the nonconducting half cycles by the energy stored in the filter capacitor. Thus, the relay will remain picked up until the anode–cathode circuit is opened by switch $S1$. Opening switch $S1$ re-establishes initial time ($t=0$) conditions. By properly coordinating the circuit components, the reset time requires only a few cycles, after which the timing cycle may be repeated.

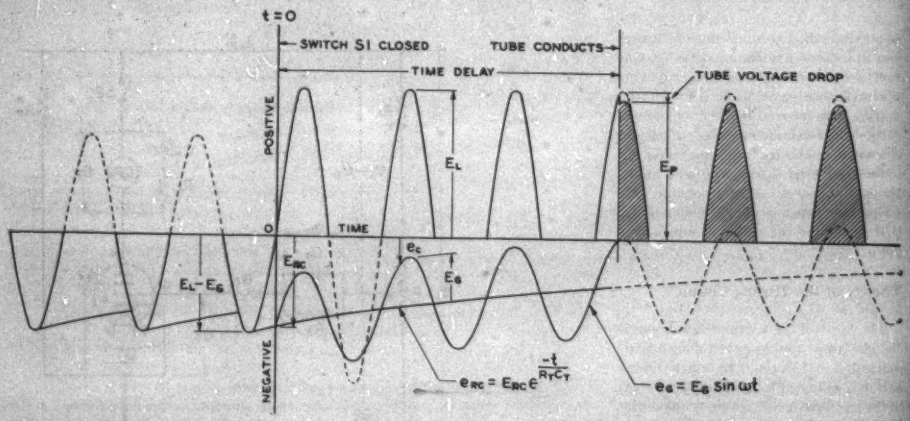

Figure 4. Instantaneous relationship of anode and control grid voltages

By merely reversing the sequence in which switches $S1$ and $S2$ are operated, essentially instantaneous energization of relay QA is obtained. With switch $S2$ open and switch $S1$ closed, the peak voltage to which timing capacitor C_T charges is approximately equal to the peak voltage of the alternating grid bias component, so that the grid is approximately at cathode potential during the positive peaks of the alternating grid bias component. That is, E_{RC} is approximately equal and in phase opposition to E_G; consequently, after switch $S2$ is closed, ionization will occur on or near the first positive peak of e_G.

External Connections

The timing relay is operated from any 120-volt a-c source connected across terminals 1 and 2, and it is controlled through a contact of the circuit breaker auxiliary switch (152) connected between terminals 1 and 3. These connections are indicated on Figure 1 by the broken lines. In a majority of cases the timing relay may be controlled directly from the circuit breaker indicating light or alarm circuits since the only requirement is energization of relay FA when the circuit breaker is open.

Contacts QA_1, QA_2, and QA_3 brought out on terminal 4-5, 6-7, and 8-9 are connected into the circuit breaker tripping circuit as shown in Figure 2. Only one of these contacts is required for multiphase potential or shunt trip methods (A and B of Figure 2), since the contacts of all the instantaneous overcurrent relays are paralleled and actuate a single trip coil. But, in the case of multiphase current or series trip methods (C and D of Figure 2) a separate contact for each instantaneous overcurrent relay is required, since these actuate separate tripping elements.

Contact QA_{10} brought out on terminal 10 may be used for initiating an alarm or operation counter.

Operation for One Instantaneous Tripout

Where instantaneous relay protection on the initial tripout with inverse-time relay protection on subsequent tripouts is desired, lever switch LS is set in the unoperated "off" position as shown in Figure 1, in which position the timing relay is set up for immediate operation to open the trip circuits of the instantaneous relays prior to the immediate initial circuit breaker reclosure.

When the circuit breaker opens, auxiliary switch contact 152 closes and ener-

gizes relay *FA* which closes the anode circuit through contact FA_4, and tube conducts immediately to energize lockup relay *QA-O*. As a result: The trip circuits of the instantaneous overcurrent relays are opened by contacts QA_1, QA_2, or QA_3; lockup relay *QA-O* is de-energized (but not released) by contact QA_6; release relay *QA-R* is connected into the anode circuit by QA_8; and the cathode is opened by contact QA_4, allowing timing capacitor C_T to charge for reset timing. All of which occurs within 0.05 second after the circuit breaker trips. This operating time provides definite assurance that the instantaneous overcurrent relays are inoperative in advance of immediate circuit breaker reclosure, since the average operating time from initiation of tripping to reclosure of circuit breakers, such as employed for feeder service, ranges from about 0.5 to 1 second.

On reclosure of the circuit breaker, auxiliary switch contact 152 opens and de-energizes relay *FA*. This closes the cathode circuit through contact FA_1, and the tube conducts after a preset time-delay to energize release relay *QA-R* which releases lockup relay *QA-O*. As a consequence, the timing relay will reset to re-establish initial conditions if the circuit breaker remains closed through a timing cycle. However, in the case of faults which are not cleared on the initial tripout, the circuit breaker will be tripped by the inverse-time overcurrent relays, and the timing relay will remain in its operated position to maintain inverse-time tripping until the circuit breaker is successfully reclosed. The reset time delay should be the minimum necessary to co-ordinate with the circuit breaker clearing time on the inverse-time overcurrent relays, in order to provide instantaneous relay protection against the contingency of rapidly recurring faults.

Operation for Two Instantaneous Tripouts

Where instantaneous relay protection on the second, as well as the first, tripout is desired, lever switch *LS* is set in the "on" position, so that contacts LS_1 and LS_3 are open, and LS_2 and LS_4 are closed. In this position the timing relay is set up for time-delay operation, since when the cathode circuit is open through contacts FA_2 and QA_7, timing capacitor C_T is precharged for timing action.

When the circuit breaker opens, auxiliary switch contact 152 closes and energizes relay *FA* which closes the cathode circuit, but the tube does not conduct until after the preset time delay. If the immediate initial reclosure is successful, relay *FA* is de-energized, and initial conditions are re-established. However, if the fault is not cleared initially, this time delay allows the circuit breaker to be tripped again by the instantaneous overcurrent relays.

In the case of faults which are not cleared on the second tripout, the tube "times out" and then energizes lockup relay *QA-O*. As a result: The trip circuits of the instantaneous overcurrent relays are opened by contacts QA_1, QA_2, or QA_3; lockup relay *QA-O* is de-energized (but not released) by contact QA_6; release relay *QA-R* is connected into the anode circuit by contact QA_8; and the cathode circuit is opened by contact QA_4 which permits timing capacitor C_T to charge for reset timing. All of which occurs prior to the second reclosure, so that subsequent tripping of the circuit breaker is initiated by the inverse-time relays.

Following a successful reclosure, the timing relay will reset in a manner similar to that described under "Operation for One Instantaneous Tripout."

Since the timing adjustment (potentiometer *P*) is common to both operation and reset, it must be such that the preceding requirements are fulfilled. In some cases, it may be desirable to have less time-delay on reset than on operation, and this is accomplished by short-circuiting a section of the timing capacitor discharging resistor as shown by the dotted connection of contact QA_{10} across resistor R_{T2} in Figure 1. The reverse can be accomplished by making QA_{10} a normally closed contact.

Conclusions

The most salient features of the timing relay are:

1. Universal application regardless of circuit breaker mechanism or method of control.
2. Selection of either one or two instantaneous tripouts.
3. Independent of the control source voltage during fault conditions.
4. Reset timing independent of reclosing relay.
5. Ease of installation.

The initial installation of this equipment was made February 1945 on a breaker serving a high exposure 24-kv grounded Y circuit. As a result long time outages previously experienced on this circuit practically have been eliminated.

Sixty similar installations will be made on the Oklahoma Gas and Electric Company system during 1946.

With certain changes in the internal wiring, this device can be converted into an instantaneous or time-delay "one-shot" recloser with quick reset on a successful reclosure.

Silicone-Resin-Treated Magnet Coils

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MAGNET COILS present somewhat different insulation problems from rotating machines. This was recognized when separate magnet coil standards[1-3] were set up by AIEE, National Electrical Manufacturers Association, and American Standards Association which permit higher maximum observable temperatures than do the rotating machine standards. AIEE Standard 1 states, "How long an insulation will last will depend not only on the class of material used but also upon the physical support of the insulation and the severity of the physical forces tending to disrupt it." Following this line of reasoning, AIEE Standards 15 and 16 permit higher observable temperatures on magnet coils as shown in Table I. Work by Erikson[4] indicates the desirability of separate consideration of magnet coils and suggests the possibility of higher operating temperatures even with organic insulation.

This distinction became more pronounced with the development of silicone insulation. Magnet coils were therefore considered as a special study of the basic work previously reported[5,6] on the general application of silicone varnishes to electric machinery. The test on coils was planned with the view of determining:

(*a*). The temperature–life relationships of the silicone varnish.

(*b*). The maximum operating temperatures of magnet coils for normal life expectancy.

(*c*). The effect of aging at various temperatures on the thermal conductivity of the assembly.

(*d*). Design advantages offered by higher temperature operation.

Test Program

Paralleling the motor test program[7] a like series of tests was planned for magnet coils. Briefly this program consisted of operating coils at different temperatures to determine the thermal life expectancy of the coils. In order that these tests might be useful and representative of standard practice, a commercial contactor and coil design were chosen. This is a conventional magnetic contactor for d-c control circuits which is widely used for industrial and railway service. The general construction is shown in Figure 1. All tests were run on this design of contactor in order that results obtained would be subject to direct comparison.

The operating temperatures from 200 to 275 degrees centigrade were chosen. The top limit was chosen because it was anticipated that at 275 degrees centigrade failures by short-circuited turns would probably occur in a few weeks. Another factor limiting the test to 275 degrees centigrade was the melting point of the solder (304 degrees centigrade) which held the coil leads to the terminals. Early estimates based on extrapolated curves for silicones indicated that 200 degrees centigrade would be the maximum operating temperature resulting in the full life expectancy of the coils. Thus the tests were started with 12 coils, three each at 200, 225, 250, and 275 degrees centigrade.

The data desired were to be obtained by day to day operating temperature readings (by resistance), mechanical stressing by thermocycling and operating the contactors, periodic measurement of cold resistances to determine wire oxidation and possible short-circuited turns (indications of failure), notation of color changes of resin on surface, and power input.

Coil Design

The coils tested were essentially a standard mechanical design to simulate normal conditions. They were wound with number 25 (0.0179 inch diameter) single glass covered copper wire (silicone varnish treated). Silicone wire enamel was not used because at that time the enamel development had not progressed far enough. All winding and insulating details were fiber glass and fiber-glass-backed mica (all bonded and treated with silicone resins). The spool was fabricated of fiber glass laminated tubes with a special resin bond (not silicone) and asbestos phenolic end washers. At the time these coils were made, thermosetting silicone moulding resins had not been developed to a usable state. The terminals were soldered with a high temperature solder (304 degrees centigrade solidifying temperature). No organic materials such as paper, cotton tape, string, glue, shellac, or varnish were used in the coil construction. The complete coil was treated by vacuum-pressure impregnation with DC-990-A silicone varnish, a product of Dow Corning Corporation, at 70 per cent solids and baked for 24 hours at 225 degrees centigrade. This was followed by a dip in 50 per cent solids DC-990-A silicone varnish and baked at 225 degrees centigrade for 16 hours.

The following design data give significant details of the coils used for this test:

Spool—$3^1/_4$ inches long by $1^9/_{32}$ inches inside diameter by 3 inches outside diameter.

Washers—1/8 inch thick.

Double insulating tube construction, each 1/16 inch thick.

Magnetic core—$1^1/_8$ inch diameter.

3,500 turns of number 25 wire having a resistance of 61 ohms (25 degrees centigrade).

Winding volume—11.6 cubic inches.

Barrel surface—25 square inches.

Test Procedure

The coils were connected to a 120-volt d-c motor generator set through variable nichrome resistors. Thus the current in each coil could be controlled without affecting the others.

The general testing procedure is detailed in Appendix I. Volt-ampere readings were taken every day, after which the coils were switched on and off ten times. Approximately once every week the cooling curves were run to check the hot volt-ampere resistance readings of each coil. The coils were then left off overnight and then cold resistance readings made the following morning, and the coils again energized.

Changes were made periodically to correct the test conditions for increases in

Table I. Comparison of Permissible Temperature Rise and Observable Temperature for Magnet Coils and for General Purposes

Class	Maximum Permissible Temperature Rise by Resistance, Deg C		Equivalent Maximum Observable Temperature,* Deg C	
	General[1]	Magnet Coils[2,3]	General[1]	Magnet Coils[2,3]
A	60	85	100	125
B	80	105	120	145

* Rise plus 40 degrees centigrade as maximum permissible ambient.

Paper 46-104, recommended by the AIEE committee on industrial control devices for presentation at the AIEE summer convention, Detroit, Mich., June 24-28, 1946. Manuscript submitted November 13, 1945, made available for printing April 11, 1946.

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Figure 1. Laboratory test setup showing magnet coils under test being examined by Mr. Torok

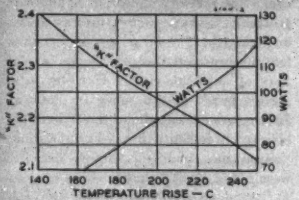

Figure 2. Effect of temperature rise on K factor and watts

cold resistance of the winding due to oxidation of the copper. After one year of operation without a failure, it was believed that the test could be made more severe by additional thermal cycling of the coils. The thermal cycling consisted of switching the power off the coils twice each day. The coils would be de-energized for approximately two hours in which time the coils would cool to a little above room temperature. Then power would be applied for four hours, a period more than sufficient for them to reach stabilized operating temperature. The power was then turned off for two hours and then left on overnight. Once each week the power would be off overnight and a cold temperature reading made the following morning.

Test Results

The change in heat dissipation factor K was used as a basis for observing insulation aging. This K factor is the average temperature rise divided by watts input and represents the temperature the coil must attain to dissipate the energy liberated within its body. Since average temperatures by resistance were used, the heat dissipating ability of the boundaries of the coil was only one factor involved. The heat transmission within the coil has an appreciable influence as it determines the distribution of temperature within the body of the coil. If the heat conductivity of the body is low, the internal temperature may be much higher than the surface temperature, where the heat is dissipated. Thus the average temperature being higher, the coil would have a very high K factor. However, if the heat conductivity within the coil were very good, the surface and internal temperature would be more nearly the same and a low K factor would result. Thus a change in K factor may represent a change in the rate of heat dissipation, but more likely the change in thermal conductivity within the body of the coil.

Aging and heat deterioration in organic and semiorganic materials generally are accompanied by weight loss, which results in dimensional changes or the formation of voids. The resinous bonds between the turns in the coil act not only as physical supports but as thermal conductors. As the impregnant ages, it shrinks or otherwise forms voids and its thermal conductivity diminishes. Resins shrink slightly as they cure and cause some voids which manifest themselves as a rise in K factor. Figure 2 shows the original K factor as a function of temperature rise above 25 degrees centigrade ambient temperature. Figure 3 shows the per cent increase in K factor as a function of hours aging under each temperature condition.

After the tests had been in progress, changes in cold resistance were observed. Thereafter periodic observations of cold resistance were made and the changes recorded. Figure 4 shows the per cent change in cold (25 degrees centigrade) resistance as a function of time of aging at various temperatures.

No definite coil failures occurred. Only two coils encountered trouble during the whole test and these were the result of faulty soldered joints at the terminal. They were detected by variable resistance readings.

Figure 5 shows the conditions of coils 2, 4, 5, 8, 9, 10, 11, and 12 after the conclusion of the test. All the coils except number 4 had been at temperature 12,615

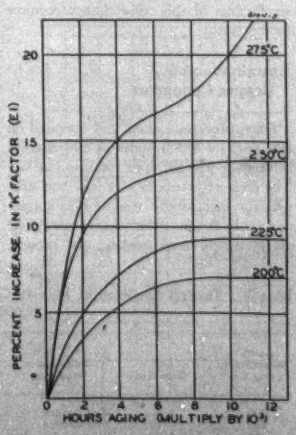

Figure 3. Effect on K factor of aging at elevated temperatures

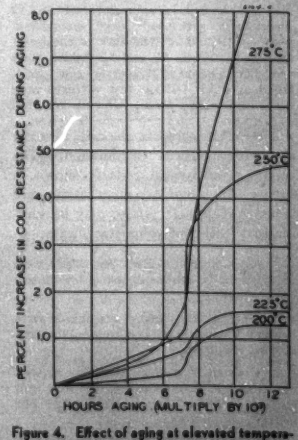

Figure 4. Effect of aging at elevated temperatures on the cold (25 degrees centigrade) resistance of magnet coils

Figure 5. Coils showing external condition after 12,000 hours aging at temperatures of 200, 225, 250, and 275 degrees centigrade

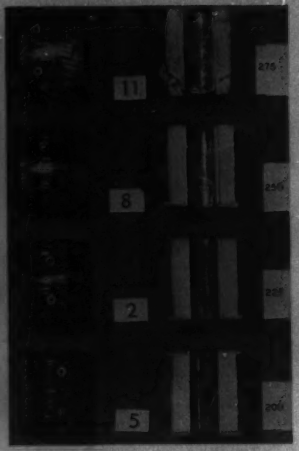

Figure 6. Coils showing internal condition after 12,000 hours aging at temperatures of 200, 225, 250, and 275 degrees centigrade

hours. Coil 4 had been at temperature 11,006 hours.

The coils shown in Figure 5 were subjected to electrical tests as follows:

(*a*). All passed the standard low-voltage short-circuit test ("E" iron balanced watt meter tester).

(*b*). All the coils except numbers 11 and 12 successfully withstood surge comparison tests[5] up to 10.6 kv (the limit of the tester available). Coils 11 and 12, which were aged 12,615 hours at 275 degrees centigrade, failed at 8 kv. These test voltages were surge peak values across two coils in series.

After electrical tests, the coils were cut open for physical examination. The condition of typical coils is shown in Figure 6. Detailed observations are given in Table II. These may be summarized in the following statements:

(*a*). Coils at 200 degrees centigrade were in excellent condition showing few if any signs of aging.

(*b*). Coils at 225 degrees centigrade were beginning to age, but were well bonded and in good condition.

(*c*). Coils at 250 degrees centigrade showed unmistakable signs of aging, but were still in fair condition, being well bonded but brittle.

(*d*). Coils at 275 degrees centigrade were still operable. However, they were in a condition which might be expected to result in failure under actual service conditions, as the bonding between wires as well as parts of the spool was near the failure point.

Thermal decomposition of silicones produces a reversal of color change from that normally encountered in organic resins. Organic resins decompose to carbon, a black conducting substance, whereas silicones decompose to silica, a white insulating substance. The aging of these coils clearly shows this color change which was an important indication. (The real significance of this color change requires further study.)

Examination of Copper Conductor

One of the coils which had operated on this test for 9,000 hours at 275 degrees centigrade was cut open for examination. The microstructure of this wire was normal for electrolytic tough-pitch copper and no hydrogen embrittlement could be detected. A black coating was present on the wire (about 0.0004 inch thick) which was found to be a mixture of cuprous and cupric oxide by X-ray diffraction analysis. The X-ray pattern for this copper was normal.

It was concluded that the test conditions had no deleterious effect on the copper wire except for slight oxidation of the surface. This surface oxidation resulted in increase in conductor resistance.

Discussion of Test Data

Over 12,000 hours (1 1/3 years) operation at temperatures of as much as 275 degrees centigrade did not destroy a single coil or produce a case of serious trouble (except the two which were attributable to original workmanship in soldering).

The change in heat dissipation factor K shows an upward trend as the coils age. The rate of increase in K factor is greater at higher temperatures as shown in Figure 3. The initial rise in K factor may be considered as indicating completion of internal cure. However, the abrupt break in the curve for coils at 275 degrees centigrade (at 8,000 hours) is believed to indicate thermal degradation.

Resistance changes, though definite, were not of a serious nature even on coils at 250 degrees centigrade for the full period of the test. At 275 degrees centigrade the resistance change shown in Figure 4 is approaching a serious condition indicating that the temperature limitation may be established by copper rather than insulation. The rate of copper oxidation is known to increase as the temperature rises. Since copper oxide at low potentials is effectively an insulator, the rate and extent of oxidation can be determined by the change in resistivity of the copper wire. Periodic coil resistance readings were necessary to determine the extent of oxidation of the windings. The cold resistances remained essentially unchanged until the test had progressed to above 6,000 hours, then they started to rise and approach a constant level except at 275 degrees centigrade. At that temperature, no saturation level was observed. This level rose at an increasing rate as the temperature

Table II. Physical Condition of Magnet Coils After Thermal Aging for Approximately 12,000 Hours

Aging Temperature, Deg C	Coil Numbers	Condition of Washers	Condition of Winding	
			Color	Bond Strength
200	4–5	Well bonded	Dark	Excellent
225	2–10	Well bonded	Beginning to lighten	Good
250	8–9	Fairly well bonded	Light	Still bonded but brittle
275	11–12	Loose	Light	Poor—ready to fall apart

rose above 200 degrees centigrade. This seems to indicate that the copper oxide forms a protective film over the copper which decelerates the oxidation for a given temperature. That the oxidation did not appear until about 6,000 hours as compared to an almost immediate rise in K factor also indicates that the silicones' adhesion to copper is good and it is the last place where voids begin to form. The extent of oxidation might be greatly reduced if the bare copper wire had a protective coating, such as cadmium plating, under the insulation.

Interpretation of Data

One of the main objectives of this program was to obtain some idea of the order of magnitude of the thermal life of the silicone resins and composite silicone insulation. A recent review[11] of the aging characteristics of insulation disclosed general agreement that thermal aging of insulation is a logarithmic function of temperature. This concept was utilized in extrapolating the results of this series of tests. Extrapolation of short time tests is recognized as difficult but if predictions are to be made, it offers at least an opportunity for an "intelligent guess."

Figure 7 has been constructed as follows to extrapolate these data:

(*a*). The actual test hours at the various temperatures were plotted as points *A*, *B*, *C*, and *D*.

(*b*). A suggested life curve for silicone insulated motors was plotted for reference, with a 12 degree centigrade slope for half-life. (By coincidence this passes through point *B*.)

(*c*). From examination and tests, it was concluded that there is little likelihood of failure at the condition resulting from the 250 degrees centigrade test (point *C*). However, the condition resulting from the 275 degree centigrade test (point *D*) was interpreted to be near the end point. These points were therefore assumed to represent minimum and maximum life and were used to locate the boundaries of the "probable failure zone." Curves then were drawn through these points parallel to the suggested life curve for silicone insulation on motors.[7]

(*d*). A reference bench mark is drawn at 7 years and reference points are shown on this line for class B motors and class B magnet coils, at temperature limits established by AIEE Standards, as indicating probable life expectancy.

From this curve, it can be seen that the probable "minimum life" curve for magnet coils intersect the bench mark line at 225 degrees centigrade. It is of interest that this is 25 degrees centigrade above the probable motor insulation life curve which is the established difference for magnet coils over motors for class A and class B insulation (see Table I). Thus the test results indicate that the increase in temperature for comparable life is consistent between motors and magnet coils with silicone insulation when compared to the present allowed temperatures for class B motors and magnet coils.

The proposed temperature allowances[9] for silicone motor insulation corresponding to AIEE Standard 1 are 160 degrees centigrade observable by resistance. This is well below the insulation life value indicated by tests on motors.[7] It, therefore, is consistent and conservative to suggest a permissible temperature for silicone magnet coil insulation below the indicated value of 225 degrees centigrade by resistance. It is the opinion of the authors that a value of 200 degrees centigrade as observed by resistance would be satisfactory.

Effect of Operating Temperature on Design

The permissible operating temperature is an important factor in magnet coil design. Temperature rise above ambient temperature can be approximated at conventional operating temperatures for a given coil design by the following formula:

$$E = \sqrt{\frac{R \times \Delta t}{K}\left(1 + \frac{\Delta t}{234.5 + t_a}\right)}$$

where

E = continuous rated voltage for temperature rise of Δt

R = cold resistance of winding at temperature of t_a

Δt = temperature rise by resistance above t_a

t_a = ambient temperature (for operating or test conditions)

K = heat dissipation constant of coil design, in degrees rise per watt

This formula assumes that the temperature rise is proportional to the watts generated in the coil winding. This is reasonably accurate until the higher temperatures are reached when the K factor tends to decrease (heat dissipation is not a linear function of temperature rise).

The relation between continuous voltage rating and temperature rise is shown in Figure 8 based on the foregoing formula. This curve also shows that the ampere turns, while increasing with rated voltage, do not increase in the same ratio because of the increase in winding resistance at the higher temperature.

From Figure 8, it is clear that the present difference between class A coils at 85 degrees centigrade rise, and class B coils at 105 degrees centigrade rise (assuming the same space factor), is somewhat less than nine per cent improvement in ampere turns. This difference is not of sufficient importance to justify the use of class B magnet coils on most applications, hence they are not used generally. To obtain a significant advantage from increase in operating temperature (with a standard size of coil), it would be necessary to increase the permissible rise from 85 degrees centigrade to approximately 160 degrees centigrade (about equivalent to one standard wire size).

Figures 9 and 10 illustrate the advantage to be gained in reduced size of winding through increase in temperature rise.

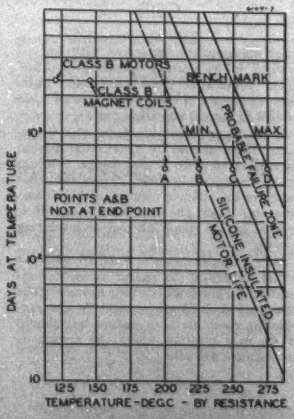

Figure 7. Thermal aging curve interpreting test results

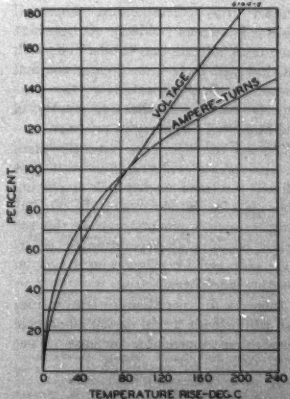

Figure 8. Effect of temperature rise on voltage and hot ampere-turns of magnet coils

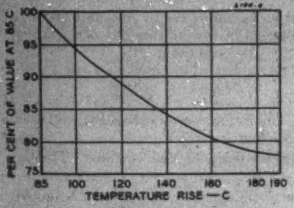

Figure 9. Effect of temperature rise on active coil length and copper weight

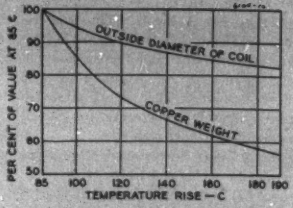

Figure 10. Effect of temperature rise on coil diameter and copper weight

These calculations are based on a constant value of minimum hot ampere turns at a specific percentage of rated voltage. The coils used as the basis for these calculations are the same size and construction as used for the tests reported herein.

Conclusions and Recommendations

One unmistakable conclusion drawn is that the combination of fiber glass and silicone resin makes an important contribution to improving the thermal life of magnet coil insulation. The end of the reliable life of such coils is believed to be determined by the failure of the silicone resins as bonds. The glass fibers provide positive turn separation and the by-products of silicone decomposition are nonconducting. Therefore, the probability of short-circuited turns is not great, even at the condition described herein as "maximum life," unless there is severe mechanical distortion of the winding.

The tests were begun about $2^1/_2$ years ago and employed DC-990-A resin which was the best silicone resin available at that time. Silicone resins have been improved (the corresponding improved resin is known as DC-993). Other short time tests indicate that similar coils with DC-993 will have even greater thermal endurance than indicated by the tests reported herein. Parallel tests employing the improved resins are in progress.

Though the experience is meager, there is considerable evidence to indicate that silicone insulated magnet coils employing fiber glass insulated wires can be rated at temperatures appreciably above the 160 degree centigrade temperature by resistance proposed for silicone insulation on rotating machinery.

Increase in permissible temperature rise will provide a real design advantage through an appreciable increase in net ampere turns. This advantage is obtained at some sacrifice in efficiency, as the watts per ampere turn are increased at elevated temperatures.

It is recommended that other investigators study this problem in order that sufficient confirming data be obtained to warrant establishing a new standard for silicone magnet coils, and particularly that they explore the elevated temperatures where designers may obtain an appreciable advantage (one standard wire size change).

It is the recommendation of the authors that an observable temperature limit of 200 degrees centigrade by resistance be considered as a future standard for silicone insulated magnet coils employing fiber glass conductor insulation. This would permit a temperature rise of 160 degrees centigrade (above 40 degrees centigrade ambient temperature) as observed by resistance.

Appendix I. Test Specification for Temperature Runs on Magnet Coils

Set up complete apparatus with coil assembled in its normal operating position. Shield apparatus from abnormal drafts where necessary but leave unrestricted room for flow of normal ventilating air.

Apply several thermocouples to coil surface. These should be distributed around the surface so as to obtain several readings for an average indication. Make sure that these are in intimate contact with coil surface and that the sensitive element is covered with a small felt pad or insulating cement.

Place a thermometer in room air adjacent to the apparatus to record ambient temperature. This should be near enough to the apparatus to indicate accurately the surrounding room air temperature but should not be in a position where the apparatus temperature will affect it.

Next accurately measure the coil resistance and record it with the coil surface temperature as well as the ambient temperature.

Only after these preliminaries should power be applied. The voltage specified for test should be held constant throughout the test. During the early part of the test, frequent readings should be taken, but in the latter part, as the coil temperature approaches a steady state, less frequent readings will suffice. Heating data should be observed and recorded as follows:

1. Time of reading with reference to cold start.
2. Volts applied to coil terminals.
3. Amperes flowing through coil.
4. Surface temperatures.
5. Room air temperature.

After all observed values reach a steady state (or the increase does not exceed the variation due to change in ambient temperature) take a set of shutdown readings. Arrangements should be made before power is shut off to change the coil connections quickly to a Wheatstone bridge. The time that power is shut off must be observed accurately and related to the cooling data taken. After power is shut off, frequent readings of coil resistance should be made until the change in coil resistance is at least half the total increase due to temperature rise. The coil resistance at the instant of shutdown is determined by plotting the values observed during the cooling period and extrapolating to the time that power was removed.

References

1. General Principles Upon Which Temperature Limits Are Based in the Rating of Electrical Machinery and Apparatus, AIEE Standard 1, June 1940.

2. American Standards for Industrial Control Apparatus, AIEE Standard 15, March 1944.

3. Standards for Electric Railway Control Apparatus, AIEE Standard 16, January 1933.

4. Insulation Temperature Standards for Industrial-Control Coils, B. W. Erikson. AIEE Transactions, volume 63, 1944, July section, pages 546–8.

5. Organo-Silicon Compounds for Insulating Electric Machines, T. A. Kauppi, G. L. Moses. AIEE Transactions, volume 64, 1945, March section, pages 90–3.

6. The Application of Silicone Resins to Insulation for Electric Machinery, J. DeKlop, L. R. Hill, G. L. Moses. AIEE Transactions, volume 64, 1945, March section, pages 94–8.

7. Silicone Insulation Proved by Test, T. A. Kauppi, Geo. Grant, G. L. Moses, R. F. Horrell. *Westinghouse Engineer*, September 1945, pages 135–40.

8. Winding-Fault Detection and Location by Surge-Comparison Testing, G. L. Moses, Earl F. Harter. AIEE Transactions, volume 64, 1945, July section, pages 490–503.

9. Magnet Coil Design, G. L. Moses. *Product Engineering*, volume 9, December 1938, pages 483–6.

10. Coils and Magnet Wire (book), Charles Rumderhill, McGraw-Hill Book Company, Inc., New York, N. Y., 1925.

11. Synthetic Insulation and the 10-Degree Rule, G. L. Moses. *Westinghouse Engineer*, July 1945, page 106.

Inductive Co-ordination Aspects of Rectifier Installations

AN AIEE COMMITTEE REPORT

THIS REPORT discusses the inductive co-ordination aspects of rectifier installations from the standpoint of effects on the a-c side and presents methods of classifying proposed installations into one of the three following categories:

Category I. Very *unlikely* to cause important induction problems.

Category II. Indeterminate.

Category III. Very *likely* to cause important induction problems.

Suggested dividing lines between categories are set up in terms of estimated harmonic currents or voltages and types of power and telephone systems involved. In using these figures, it is important to keep in mind that the phenomena involved are complex and that simple estimates are necessarily approximate: a difference of less than about 25 per cent in any of the results obtained by these estimates is ordinarily not significant. It is particularly important that none of the figures be construed to be any sort of limit. (For working material, see pages 420 and 421.)

Among the advantages of classification of installations in the manner described herein are:

1. Considerable time and effort can be saved by avoiding useless detailed studies and tests in connection with installations which simple analyses would show to be relatively innocuous, that is, to be in category I. After an installation in this category is placed in service, a few tests may be made to check the indications of the rough estimates and catalogue the case for future reference.

2. It will be easy to recognize those installations in which the only way to find out definitely whether remedial measures are needed—and if so the best type—is by detailed tests of power system influence and telephone noise before and after the rectifier is put into operation, that is, installations in category II.

3. The occasional situation in which the rectifier load would cause immediate and severe problems, that is, installations in category III, can be recognized and suitable precautions taken. These precautions are, usually, to provide remedial measures in advance, or if this is not feasible, to confine the harmonics to areas where they can do little harm until tests can be made and remedial measures designed and installed.

4. It will facilitate co-operative advance planning, for example, selection of methods of power supply and number of phases, to minimize the probability of important induction problems.

5. Where tests are required, it will facilitate setting up test programs to obtain information of the maximum usefulness with minimum effort.

While this report is devoted primarily to rectifiers of the sort usually encountered in industrial, railway, and radio applications, methods are given later for treating certain of the types encountered less frequently. The following matters pertaining to harmonics associated with rectifiers are not covered, but references to other information are included as indicated:

1. Harmonics on the d-c side of rectifiers (see items 21, 32, 33, 34, 35, and 36 in References).

2. Effect of harmonics on the a-c side on heating of power equipment and on balance of rectifiers (see items 3, 16, and 31 in References).

3. Single-phase rectifiers (see item 36 in References).

More complete treatments of specific aspects of the subject are contained in the literature listed under References, which are referred to in the following text. Appendixes I and II contain, respectively, brief discussions of the fundamentals of induction and of the propagation of harmonic currents and voltages over power circuits, which may be found useful in obtaining a more comprehensive picture of the phenomena involved. Appendix III gives pertinent data on a few of the installations which have been studied.

Nature of Problem

In this section are discussed the basic factors of the inductive co-ordination problem relating to rectifier installations from the point of view of the a-c power system. An understanding of these factors will be helpful in analyzing situations involving inductive co-ordination problems and in finding remedial measures.

Factors Affecting Problem

Considering the a-c side of a rectifier installation, the only significant effect of the installation from the inductive co-ordination standpoint is the production of harmonic currents and voltages in the power system.[1, 2, 3, 8, 9, 17, 20, 21, 23, 24, 33] These harmonic currents and voltages set up magnetic and electric fields of corresponding frequencies about the power lines; they, in turn, may induce voltages of the same frequencies in paralleling telephone circuits which may cause noise in these circuits. Induction caused by power circuit currents is called magnetic; that caused by power circuit voltages is called electric (see Appendix I). Whether noise problems will occur and, if so, their severity and extent, will depend on the magnitudes of the harmonic currents and voltages at various places over the power system, the characteristics of the power system, the amount, type and location of situations of proximity between power and telephone circuits (that is, "exposures"), and the characteristics of the telephone circuits. These matters are discussed more fully in Appendix I.

Generation of Harmonics

The current taken by a rectifier unit from the a-c line has a step-type wave shape resulting from the flat top wave shape of the anode currents. Typical wave shapes of rectifier a-c line currents are shown in Figure 1.

Table I shows the orders (that is, the multiples of the fundamental frequency) of the harmonics on the a-c circuits associated with rectifiers of different numbers of phases. The magnitude of any harmonic which is present with any particular number of phases is the same as for a 6-phase rectifier if all other conditions are the same. For example, the magnitudes of the twenty-third and twenty-fifth harmonics are approximately the same whether the rectifier has 6, 12, or 24 phases.[2, 3, 8, 9, 20, 31]

The magnitudes of the harmonic currents have a definite relation to the magnitude of the total rectifier current and also depend on the order of the harmonic. The higher the order of a harmonic, the smaller is its magnitude.

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This report was prepared by a working group of the electronic power conversion subcommittee, AIEE committee on electronics, consisting of H. R. Huntley (M '29, *chairman*), operation and engineering department, American Telephone and Telegraph Company, New York, N. Y.; R. D. Evans (F '40), consulting transmission engineer, Westinghouse Electric Corporation, East Pittsburgh, Pa.; C. W. Frick (A '19), general engineering laboratory, General Electric Company, Schenectady, N. Y.; H. E. Kent (M '31), engineer, Edison Electric Institute, New York; H. Winograd (M '39), engineer in charge, rectifier design, electrical department, Allis-Chalmers Manufacturing Company, Milwaukee, Wis.

Effect of Power Circuit Impedance

In Figure 2 is shown a simple power supply circuit for a rectifier installation. The rectifier unit R is supplied from a power source G over a 3-phase line A. The power supply circuit has an impedance Z, which includes the impedances of the line and the power source. From the point of view of the power circuit, the rectifier unit can be considered as a generator of harmonic currents. The impedance of the power supply circuit will effect some reduction in the harmonic currents, the extent of the reduction depending on the magnitude of the impedance.

If a harmonic current I_n flows from the rectifier over the line to the power source, a voltage drop in the line will result because of the impedance Z_n of the power circuit at the harmonic frequency. This will produce at point S a harmonic voltage $E_n = I_n Z_n$. If a communication circuit should have an exposure to the power line A, experience shows that the controlling inductive effect in such a case is almost always caused by the harmonic current rather than by the harmonic voltage; the latter can, therefore, be neglected without much error for an exposure to the main supply feeder.

However, if the power line should have an extension B for supplying other loads, as shown in Figure 3, the harmonic voltage at S will cause a harmonic current to flow over that line also, although the power to the rectifier is supplied only over line A. This harmonic current in, as well as the harmonic voltage on, line B and any lines that may branch from it could cause induction in communication lines exposed to them.

The higher the value of impedance Z_n the greater will be the harmonic voltage at S and the higher the magnitude of the harmonic current flowing over line B. Actually, the harmonic currents from a rectifier can flow into any part of an a-c system to which it is connected, as determined by the impedances of the various branches of the system at the harmonic frequencies, regardless of the location of the source of power supply or the direction of power flow.[18,19] In practice, however, the circuit over which the rectifier receives its power usually has the lowest impedance and draws the greater part of the harmonic currents.

Table I. Harmonics Arising in Rectifiers

Orders of Harmonics Present With Balanced Operation*						Harmonic Frequencies on 60-Cycle System, Cycles
6-Phase Rectifier	12-Phase Rectifier	18-Phase Rectifier	24-Phase Rectifier	36-Phase Rectifier	48-Phase Rectifier	
5	—	—	—	—	—	300
7	—	—	—	—	—	420
11	11	—	—	—	—	660
13	13	—	—	—	—	780
17	—	17	—	—	—	1,020
19	—	19	—	—	—	1,140
23	23	—	23	—	—	1,380
25	25	—	25	—	—	1,500
29	—	—	—	—	—	1,740
31	—	—	—	—	—	1,860
35	35	35	—	35	—	2,100
37	37	37	—	37**	—	2,220
41	—	—	—	—	—	2,460
43	—	—	—	—	—	2,580
47	47	—	47	—	47	2,820
49	49	—	49**	—	49**	2,940
53	—	53	—	—	—	3,180
55	—	55**	—	—	—	3,300
59	59	—	—	—	—	3,540
61**	61**	—	—	—	—	3,660**

* Other harmonics may be present if the rectifier is unbalanced, as by differences in load or phase control between units, or by harmonics in the power supply.

** The series continues above these values.

Effect of A-C Line Voltage

For a given kilovolt-ampere input to a rectifier installation, the higher the a-c line voltage the lower is the a-c line current and the lower the magnitude of the harmonic currents, because the magnitude of the harmonic current components has a definite relation to the rms value of the rectifier current. When the harmonic currents are lower, usually the harmonic voltages produced by them are also lower. Also, there are fewer long close exposures of telephone circuits to high-voltage transmission circuits than to power distribution circuits. Thus as the voltage of the line supplying a rectifier installation is increased, the probability of interference in communication circuits in the vicinity of the rectifier installation is decreased.

Harmonic currents and voltages can be transmitted through power and distribution transformers in the a-c system and their magnitudes changed in accordance with the transformation ratios of the transformers. However, the factors controlling the propagation of harmonics over power networks are different quantitatively from those controlling the fundamental, as discussed in more detail in Appendix II.

Effects of Phase Control

Phase control is used on a rectifier for the purpose of reducing the d-c output voltage below the value obtained without phase control. It is accomplished by retarding the firing point of the anodes in the alternating-voltage cycle, through grid or firing control. When phase control is used, there is no change in the transformation ratio of the rectifier transformer, and the ratio between the rectifier d-c current and the a-c line current remains practically unchanged.

If the d-c output is maintained constant while the d-c output voltage is reduced by phase control, the kilowatt output of the rectifier unit is reduced while the magnitude of the a-c line current and the kilovolt-ampere input remain unchanged, the power factor at the a-c line terminals of the rectifier transformer being lowered thereby. The result is that the magnitude of the harmonic components in the a-c line current, per kilowatt output of the rectifier, is increased.

Phase control also produces a steeper rise and fall of the anode currents at the beginning and the end of the anode firing period, while the current is commutated between successive anodes (see Figure 4). This is reflected in a steeper change of current between successive steps of the a-c line current wave, which results in harmonic components of higher magnitude.[5,9]

These effects increase as the amount of phase control employed is increased. The use of an appreciable amount of phase control is therefore likely to increase the co-ordination problem between a power system supplying rectifiers and communication circuits. It is important, therefore, that the use of phase control in excess of actual requirements be avoided, particularly in the range of full-load and overload ratings of rectifiers.

I·T Product and Voltage TIF

In the remainder of the body of the report, the terms "I·T product" and "voltage TIF" are used freely. These terms are discussed in Appendix I. At this point it is sufficient to note that I·T prod-

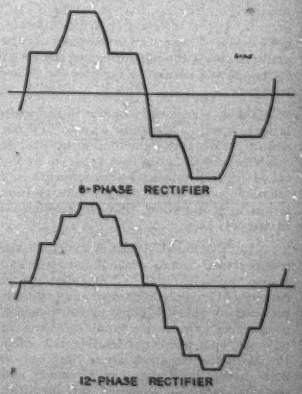

Figure 1. A-c line currents

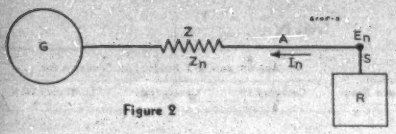

Figure 2

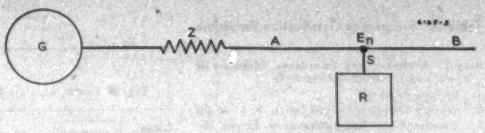

Figure 3

uct is a measure of the over-all noise influence of a current (including fundamental and harmonics); voltage TIF is a similar measure for voltage of known rms value.[27,28]

Ground Return and Balanced Harmonics

Harmonics arising in rectifiers supplied on a 3-phase basis start out as balanced, that is, the phase currents are equal and 120 degrees apart, as are also the phase-to-neutral voltages. If the power system were perfectly balanced, that is, if at harmonic frequencies the series impedances of the three phase wires were equal and also if the admittances to ground of these wires were equal, these currents and voltages would remain balanced. However, with three or more wires on a pole head, the series impedances of the different wires are usually not identical nor are the admittances to ground identical. In many cases these inequalities are accentuated by the presence of single-phase branches and single-phase loads. As a result, on distribution circuits (and to a limited extent on transmission circuits), the vector sum of the harmonic phase currents or of the phase-to-ground voltages is not zero; the vector sum is called "residual." That part of the residual harmonic current which returns in the ground is called "ground return"; it has a larger inductive effect than currents confined to the wires. Similarly, the effect of residual voltages is larger than that of balanced voltages. These matters are discussed in more detail in Appendix I.[10,11,12,23]

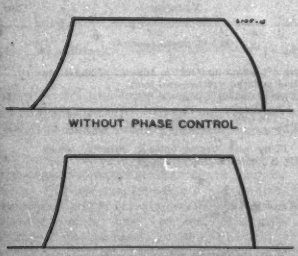

Figure 4. Anode currents

Relations Between Harmonic Voltage and Harmonic Current

Harmonic voltages on a power system may be important from two standpoints, namely:

1. Where open wire telephone circuits are involved, the induction from these voltages may be important.

2. In many situations, the more important effect of harmonic voltages is in causing harmonic currents in parts of systems on which these voltages are impressed. For example, in Figure 3 the effect of a harmonic voltage E_n in causing a harmonic current in part B of the system is likely to be more important than the direct effect of E_n. This is particularly likely to be true if part B is unbalanced, as by single phase branches and loads, so that part of the current becomes ground return.

In connection with 1 above, the harmonic current into B at any frequency f_n is the impressed harmonic voltage of that frequency E_n divided by the impedance looking into B at that frequency. This impedance is not the series impedance of the wires of B alone; it depends not only on these series impedances but also on the impedances in shunt with the circuit, such as, for example, the impedances of loads or capacitors connected to the circuit and of the capacitances of the wires to each other and to earth. All of these impedances vary with frequency—some directly, some inversely, and some in a complex manner. Estimating the I·T on an actual circuit under these conditions would, therefore, be quite involved. For rough estimates only, it has been found useful to assume a direct relation between the voltage TIF on the circuit and ground return I·T.

Procedure in Classifying Proposed Installations

On pages 420 and 421 are shown the steps involved in the classification of a proposed rectifier installation together with essential data and equations. In the remainder of this section, these steps and data are discussed.

Step 1 (Refer to Table III, Page 420)

It is convenient to start with a schematic diagram of the power supply system. A typical diagram, shown in Figure 5A, includes the rectifier and its transformer, the supply feeder and its transformer, and associated power sources which may involve generators, a supply network, or both. In addition, the location of present or proposed telephone circuits, in relation to power circuit feeders, should be determined as illustrated by exposures to power feeders A, B, C, and N. These exposures illustrate the groupings that are convenient in classifying installations from the co-ordination standpoint. While in a detailed study it is necessary to have rather complete information on exposure conditions, it usually is sufficient for classification purposes to know their general type and extent; for example, the extent to which the power circuits are or are likely to be involved in joint use of poles with telephone cables or in joint use or roadway exposures to telephone open wire.

It is usually convenient, next, to draw an impedance diagram similar to Figure 5B. In this diagram the reactances of the various parts of the circuit through which power flows to the rectifier are indicated as percentages on the total rectifier transformer kilovolt-ampere base. If the rectifier transformer kilovolt-amperes is known, it is used directly; if it is not known, a sufficiently good approximation for the present purpose can be obtained from equation 1. The per cent commutating rectance ($\%X_{cn}$) of the rectifier transformer can be obtained from the manufacturer or can be approximated from Table II.*

* The per cent impedance given on rectifier transformer nameplates should not be used because it applies only to the case where voltage is applied to the primary, and all of the secondary terminals are short-circuited.

Table II. Approximate Per Cent Commutating Reactance of Rectifier Transformers

Voltage Class on A-C Side, Kv	Approximate Reactance, Per Cent: Rectifiers for Railway and General Industrial Service	Rectifiers for Electrochemical Processes
Up to 15	5	9
34.5	6	9
69	8	9
115	10	10
161	12	12
230	14	14

Table III. Summary of Classification Procedure

Step 1. Schematic and Impedance Diagrams of Power Supply System (see Figure 5)

1. Indicate exposures
2. Classify circuits as to type (as *A*, *B*, *C*, or *N*)
3. Determine per cent reactance of circuit elements at 60 cycles on total rectifier transformer kilovolt-ampere base
   - *A.* Commutating reactance of rectifier transformer from Table II or from manufacturer
   - *B.* 60-cycle power source reactance (use name plate data or Tables VIII and IX for reactances, and equations 4 and 5 for conversion to rectifier transformer kilovolt-ampere base)
   - *C.* Rectifier feeder (see equations 2 and 3)
4. Obtain *total* per cent commutating reactance (total $\%X_R$) on total rectifier transformer kilovolt-ampere base by combining items 3A, 3B, and 3C above; or
5. If data on reactances are not available, assume total per cent commutating reactance of eight per cent for industrial and railway installations supplied from distribution circuits and the values in Table II plus two per cent for all other installations

Step 2. Direct-Feeder Exposure (Exposure A, Figure 5)

1. If phase control is not used at rectifier rated load, estimate I·T product from Figure 6
   - *A.* Interpolate between curves, using total $\%X_R$ obtained in item 4 or 5 of step 1
   - *B.* Divide ordinate by phase-to-phase voltage in kilovolts and multiply by total rectifier transformer kilovolt-amperes
2. If phase control is used at rated load, obtain I·T product as discussed under "Substantial Amounts of Phase Control" rather than from Figure 6
3. Classify exposure as in Table IV*

Step 3. Indirect Distribution Exposures (Exposure B and C of Figure 5)

1. If phase control is not used at rectifier rated load, estimate voltage TIF on bus supplying feeder *B* or *C*, from Figure 7
   - *A.* Interpolate between curves, using total commutating reactance ($\%X_R$) obtained in item 4 or 5 of step 1
   - *B.* Multiply ordinate by per cent reactance from (and including) 60-cycle power source to point of power supply to feeder *B* or *C*
2. If phase control *is* used at rated load, obtain voltage TIF as discussed under "Substantial Amounts of Phase Control" rather than from Figure 7
3. Classify exposure as in Table V*

Step 4. Exposures to Supply System Network (Exposure N, Figure 5)

1. Starting with the I·T product obtained in step 2
   - *A.* Obtain division of this I·T product between network (*N*) and generator (*G*) on basis of their inverse impedances
   - *B.* Multiply *network* I·T from (*A*) above, by line voltage of direct feeder (*A*) and divide by line voltage of the *network*
2. Classify exposures as in Table VI*

Estimates of per cent reactance of other circuit elements on total rectifier transformer kilovolt-ampere base can be obtained from equations 2, 3, 4, and 5. The following suggestions may be of help in estimating reactances to use in these equations:

1. For generators and other synchronous

* In Tables IV, V, and VI, the classification of installations into categories has the following general significance:

Category I. Very *unlikely* to cause important induction problems.

Category II. Indeterminate.

Category III. Very *likely* to cause important induction problems.

Table IV

Type of Feeder A	Type of Telephone Plant	Approximate I·T Product on Feeder A for Category I*	Category II*	Category III*
Cable	All	All	—	—
Overhead circuit, but so located that there are and will be no exposures more than a few spans long	All	All	—	—
Overhead distribution circuits with normal existing or possible future exposures	Cable†	Less than about 10,000	About 10,000 to about 100,000	More than about 100,000
	Long open wire	Less than about 5,000	About 5,000 to about 50,000	More than about 50,000
Rural,‡ with present or possible future exposures	Long open wire	—	All	—

† With or without short open-wire extensions. ‡ Feeder of low capacity with single-phase loads.

Table V

Type of Distribution Circuit Involved in B and C	Type of Telephone Plant	Approximate Voltage TIF on B or C for Category I*	Category II*	Category III*
Cable	All	All	—	—
Overhead, so located that no exposures more than a few spans can exist	All	All	—	—
Overhead, urban, with no capacitors more than a few blocks away from the rectifier	Cable†	Less than about 50	About 50 to about 150	More than about 150
Overhead, urban with a likelihood of capacitors some distance away	Cable or open wire	Less than about 40	About 40 to about 100	More than about 100
Overhead circuit supplying scattered industrial and residential loads in relatively open country and without extensive single-phase branches	Long open wire	Less than about 30	About 30 to about 75	More than about 75
Rural‡	Long open wire	Less than about 20	About 20 to about 50	More than about 50

† With or without short open-wire extensions. ‡ Feeder of low capacity with single-phase loads.

Table VI

Characteristics of Supply System	I·T Product Into the System (N) Category I*	Category II*	Category III*
Extensive cable networks of type found in large cities	All	—	—
Overhead subtransmission systems	Less than about 20,000	About 20,000 to about 100,000	Over about 100,000
Extensive high-voltage transmission systems:			
A. Rectifier with 6–24 phases	Less than about 5,000	5,000 to 25,000	Over 25,000
B. Rectifier with 30–48 phases	Less than about 10,000	10,000 to 50,000	Over 50,000
C. Rectifier with 72 or more phases	All	—	—

Table VII. Equations Used in Estimating Reactances Associated With Rectifier Installations

Nature of Reactance	Equation	Number
To estimate: A-c line kva of rectifier transformer (kva)R from rectifier kw and phase control	$\text{kva}_R = 1.15\,\frac{(100+\%\text{ phase control})}{100} \times \text{rectifier kw}$ Here "% phase control" is amount of phase control at rated voltage and load	(1)
	$\%X_L = (0.00375)(L)\,(\text{kva}_R)$ for 4-kv circuits	(2)
	$\%X_L = \frac{(0.075)(L)(\text{kva}_R)}{E_L^2}$ for 13-kv and higher-voltage circuits, where E_L is phase-to-phase voltage, in kv	(3)
To find: Per cent reactance ($\%X_{R_2}$), on rectifier transformer kva base (kva_R), of equipment having a known per cent reactance ($\%X_a$) with respect to some other kva base (kva_a)	$\%X_{R_2} = \%X_a \frac{\text{kva}_R}{\text{kva}_a}$	(4)
Per cent reactance ($\%X_{R_2}$), on rectifier transformer kva base (kva_R), of a reactance given in ohms (X_a) in a line of voltage E_L	$\%X_{R_2} = (X_a)\,\frac{(\text{kva}_R)}{10E_L^2}$ E_L is phase-to-phase voltage, in kv	(5)

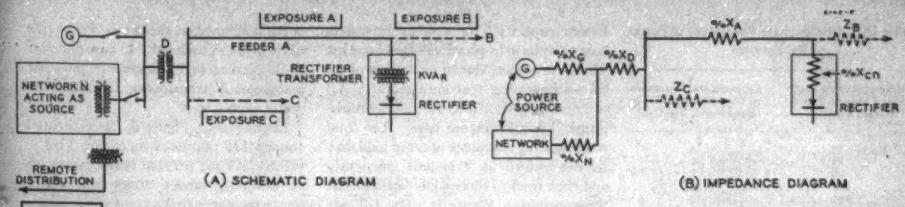

Figure 5. Typical power-supply and telephone exposure diagram for classifying rectifier co-ordination problems

A = feeder to rectifier
B = distribution system extending beyond rectifier station
C = distribution system fed from supply substation
D = transformer bank supplying distribution system
G = generator
$\%X_{cn}$ = per cent commutating reactance of rectifier transformer
$\%X_A$ = per cent reactance of feeder A, on rectifier transformer kilovolt-ampere base
$\%X_D$ = per cent reactance of transformer D, on rectifier transformer kilovolt-ampere base
$\%X_G$ = per cent reactance of generator G, on rectifier transformer kilovolt-ampere base
$\%X_N$ = per cent reactance of network N, on rectifier transformer kilovolt-ampere base
Z_B = impedance presented by distribution circuit B, to voltages of nth harmonic frequency
Z_C = impedance presented by distribution circuit C, to voltages of nth harmonic frequency

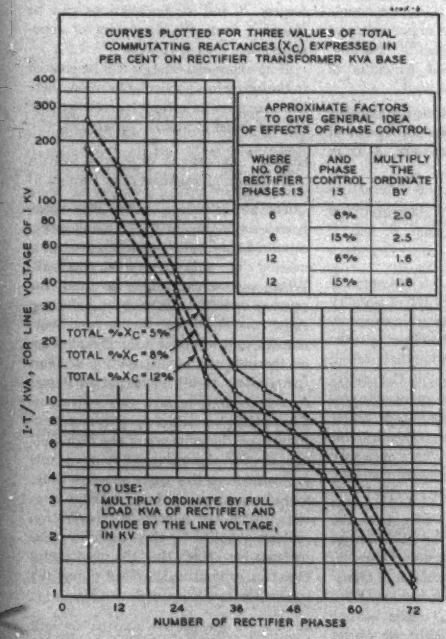
CURVES PLOTTED FOR THREE VALUES OF TOTAL COMMUTATING REACTANCES (X_C) EXPRESSED IN PER CENT ON RECTIFIER TRANSFORMER KVA BASE
APPROXIMATE FACTORS TO GIVE GENERAL IDEA OF EFFECTS OF PHASE CONTROL
WHERE NO. OF RECTIFIER PHASES IS | AND PHASE CONTROL IS | MULTIPLY THE ORDINATE BY
6 | 8% | 2.0
6 | 15% | 2.5
12 | 6% | 1.6
12 | 15% | 1.8
TOTAL %XC=5%
TOTAL %XC=8%
TOTAL %XC=12%
TO USE: MULTIPLY ORDINATE BY FULL LOAD KVA OF RECTIFIER AND DIVIDE BY THE LINE VOLTAGE, IN KV
I·T / KVA, FOR LINE VOLTAGE OF 1 KV
NUMBER OF RECTIFIER PHASES

Figure 6. I·T per kilovolt-ampere of rectifier transformer capacity for 1-kv line voltage versus number of rectifier phases (60-cycle systems)

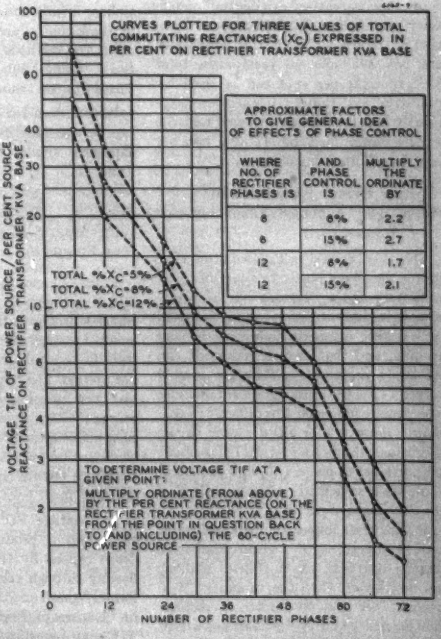
CURVES PLOTTED FOR THREE VALUES OF TOTAL COMMUTATING REACTANCES (X_C) EXPRESSED IN PER CENT ON RECTIFIER TRANSFORMER KVA BASE
APPROXIMATE FACTORS TO GIVE GENERAL IDEA OF EFFECTS OF PHASE CONTROL
WHERE NO. OF RECTIFIER PHASES IS | AND PHASE CONTROL IS | MULTIPLY THE ORDINATE BY
6 | 8% | 2.2
6 | 15% | 2.7
12 | 6% | 1.7
12 | 15% | 2.1
TOTAL %XC=5%
TOTAL %XC=8%
TOTAL %XC=12%
TO DETERMINE VOLTAGE TIF AT A GIVEN POINT: MULTIPLY ORDINATE (FROM ABOVE) BY THE PER CENT REACTANCE (ON THE RECTIFIER TRANSFORMER KVA BASE) FROM THE POINT IN QUESTION BACK TO AND INCLUDING) THE 60-CYCLE POWER SOURCE
VOLTAGE TIF OF POWER SOURCE / PER CENT SOURCE REACTANCE ON RECTIFIER TRANSFORMER KVA BASE
NUMBER OF RECTIFIER PHASES

Figure 7. Source voltage TIF per per cent source reactance on rectifier transformer kilovolt-ampere base versus number of rectifier phases (60-cycle systems)

machinery, the average of the subtransient and negative sequence reactances may be used. If these reactances are not known, the approximate percentages on the machine kilovolt-ampere base, shown in Table VIII,[14,17] may be used.

2. If the reactance of a power transformer bank is not known, the approximate figures in Table IX may be used.

Table VIII. Approximate Reactances of Synchronous Machines

Type of Machine	Reactance on Own Base for Use in Equation 4, Per Cent
2-pole turbine generator	9
4-pole turbine generator	15
Salient pole generator or motor	
With dampers	24
Without dampers	45
Synchronous condenser	35

3. Where the "network acting as power source" includes a transformer bank between the lines and the bus, about the best approximation is to consider the impedance, looking into it from the bus as being equal to the reactance of the transformer bank alone. This approximation is good if the network is

Table IX. Approximate Reactances of Power Transformers

Voltage Class on High-Voltage Side of Transformer, Kilovolts	Approximate Reactance on Own Base for Use in Equation 4, Per Cent
Up to 15	5
34.5	7
69	8
115	10
161	12
230	14

a high voltage system; it gets successively poorer as the voltage of the network approaches that of the bus.

Having set down the reactances as percentages on the total rectifier transformer kilovolt-ampere base, they are combined to obtain the approximate total commutating reactance in per cent on rectifier transformer kilovolt-ampere base, that is, total $\%X_c$.* In cases where data are not available on reactances, total $\%X_c$ of eight per cent can be used for industrial and railway installations supplied from distribution systems and the values shown in Table II plus two per cent for all other installations.

Step 2. Direct Exposures to Rectifier Feeders (Exposure *A* in Figure 5)

Step 2 covers a direct distribution type feeder supplying power to a rectifier. As indicated under "Nature of Problem," experience indicates that in practically all such cases, magnetic induction is controlling, and that electric induction can be safely neglected. While the ground return I·T is the most significant measure of magnetic influence, it is difficult to estimate; however, for given power circuit conditions, the ground return I·T is about proportional to phase I·T, and the latter provides a sufficiently reliable indication for classification purposes.

It has been found for installations of ordinary rectifiers of a given number of phases operated at full load without phase control, that the quantity "I·T product per kilovolt-ampere of rectifier transformer capacity" usually lies within a fairly narrow range. In Figure 6 are plotted average values of "I·T product per kilovolt-ampere of rectifier transformer capacity" for a 60-cycle system having a phase-to-phase voltage of one kv. Three curves are shown for values of total commutating reactance (total $\%X_c$) of 5%, 8%, and 12% on the rectifier transformer kilovolt-ampere base. The total commutating reactance at rated load may be determined as explained previously and then used to interpolate between the three curves of Figure 6. The I·T per kilovolt-ampere thus obtained, when multiplied by the rectifier transformer kilovolt-amperes and divided by the a-c phase-to-phase voltage in kilovolts, will give the I·T product for feeder *A*. The data from Figure 6 also apply if phase control is used only at fractional load or if small amounts of phase control (not over a few per cent) at full load are used to balance loads among units forming a multiphase installation.** If larger amounts of phase control are used in normal operation, the methods outlined in "Installations Using Substantial Amounts of Phase Control" should be used.

With known I·T product, installations can be classified from the standpoint of exposures similar to exposure *A* as in Table III.

Step 3. Indirect Distribution Exposures (Exposures *B* and *C* of Figure 5)

From the standpoint of exposures *B* and *C* in Figure 5, the factor of primary interest usually is the ground return I·T product. This factor, however, is very difficult to estimate, and for that reason, the voltage TIF impressed on the feeders and their extent and type are usually employed. This approximation is rather poor quantitatively but is good enough for classification purposes. Where open wire telephone circuits are involved, the voltage TIF itself is of importance.

The voltage TIF on feeder *C* at the substation is produced by the voltage drops caused by the harmonic currents flowing through the reactances of transformer bank *D* and the source as explained in "Nature of Problem." The voltage TIF may be estimated with the aid of Figure 7. The value of the total commutating reactance obtained in step 1 is used to interpolate between the curves of Figure 7. The ordinate thus obtained for the particular number of rectifier phases is the voltage TIF contribution per "per cent power source reactance" on the rectifier transformer kilovolt-ampere base. This value when multiplied by the appropriate per cent power source reactance gives the voltage TIF on the feeder. "Power source reactance," as here used, is the reactance on the power source side of the point considered. In case of feeder *C*, the power source reactance includes the reactances of transformer *D* and of the power supply to it.

In thus using Figure 5, the estimated voltage TIF impressed on feeder *B* is the voltage TIF per per cent source reactance as estimated above times the power source reactance to the point where feeder *B* is supplied. The per cent source reactance to the point where feeder *B* is supplied is equal to the source reactance used for feeder *C* plus the per cent reactance of feeder *A*. The reactance of feeder *A* can be determined conveniently from equation 2 or equation 3, depending on the circuit voltage.

Having obtained estimates of voltage TIF at the points supplying power to feeders *B* and *C*, installations can be classified from the standpoint of exposures *B* and *C* as in Table V.

If no exposures exist or will be created in the future in a particular location, there is no occasion for estimating voltage TIF for that feeder location or supply bus.

Step 4. Exposures to Supply System Network (Exposure *N* in Figure 5)

The power supply system may range from a single generator *G* to many generators and may include an extensive transmission or subtransmission network. Where such a network is involved, the primary consideration from an induction standpoint is whether the harmonic current fed to it will have a significant effect on the influence of distribution systems (particularly rural) connected to it and over how large an area this will occur. The rectifier harmonics do, of course, tend to increase the influence of the high voltage circuits themselves, but as a rule problems from this cause are less widespread or important than problems associated with the effects on distribution systems supplied by these circuits. Experience has shown that the most useful factors in estimating the effect of rectifier harmonics from this standpoint are:

1. The I·T product put into the network by the rectifier.
2. The general characteristics of the network.

The I·T product on the direct feeder *A* has already been obtained in step 2. This I·T product will divide between the generator and network circuits in the inverse ratio of their impedances, from which the I·T product put into the network can be estimated. Where the network is connected to the bus through a transformer bank, the impedance looking into the

* For rectifier installations of 12 or more phases, strict theoretical accuracy would require application of correction factors to the a-c system reactances before combining them with the commutating reactance of the rectifier transformer to obtain total $\%X_c$. For the purposes of this report, this refinement was not considered essential and was omitted for the sake of simplicity.

** It has been found by experience that the minimum I·T is secured when the loads among units in a multiphase installation are well balanced even if this requires the use of small amounts of phase control in some of the units.

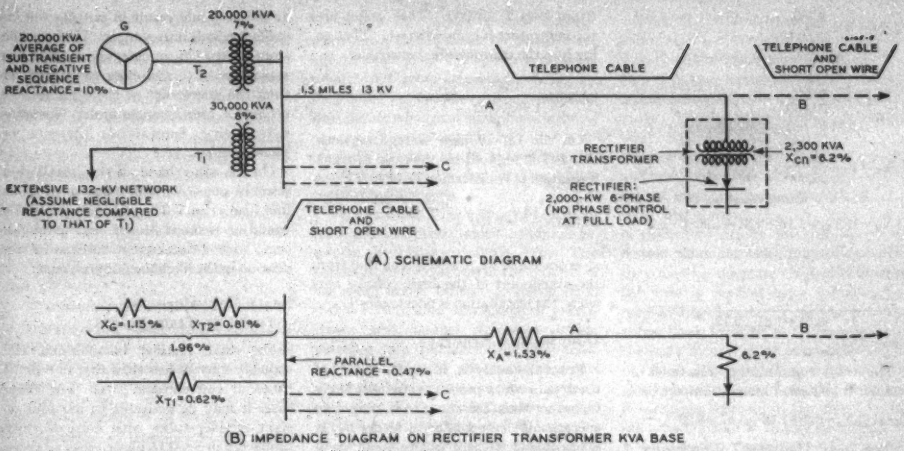

Figure 8. Illustrative example of installation to be classified

network can be assumed to be that of the transformer bank; where there is no transformer bank, the safest assumption is that all of the I·T goes into the network. In estimating magnitude of I·T products at various points, it is, of course, necessary to take into account the ratios of any transformers through which the currents pass.

While a wide range of supply network and exposure conditions may be encountered, the most useful and convenient classification from the co-ordination standpoint is based on the information outlined in Table VI.

Discussion

Rectifier co-ordination problems involve complex phenomena. As a consequence, a few installations which appear to be in category I cause important problems; conversely, a few installations which appear to be in category III turn out to be innocuous. Categories I and III have been set up so as to make them as definite as practicable, while category II covers a wide range of intervening conditions. The chance of a particular case's actually falling outside of its indicated range depends to a considerable extent upon its nearness to the edge of the range.

Certain additional factors may be considered qualitatively in estimating the likelihood of important induction problems for installations, particularly those in category II. Some favorable and unfavorable factors in exposures to distribution circuits (exposures *A*, *B*, and *C* of Figure 5) are:

1. Heavy industrial type feeders supplying mainly 3-phase loads provide a favorable factor. The lighter the load, the more scattered it is; and the larger the proportion of single-phase line and load, the greater will be the likelihood of a co-ordination problem, assuming normal urban exposure conditions.

2. Large banks of capacitors at or near rectifier installations of 12 or more phases are usually favorable; for 6-phase installations they may be favorable or unfavorable. The reason for the differentiation is that resonance between capacitors and urban distribution circuits is most likely to be important for frequencies of from 200 to 500 cycles, which are normally suppressed with rectifiers of 12 or more phases.

3. Capacitor banks electrically remote from rectifier installations may be unfavorable, particularly for 6-phase rectifiers.

Certain additional favorable and unfavorable factors in exposures involving the supply network (exposure *N* of Figure 5) are:

1. For urban power cable networks, the greater the lengths of cable which the harmonics must traverse before reaching overhead circuits, the less is the likelihood of a problem.

2. The larger the number of transformers through which the harmonics must pass before they reach overhead distribution circuits, particularly rural circuits, the smaller is the likelihood of a problem.

3. Supply to a rectifier direct from a generator bus is favorable; a generating station connected to a high voltage transmission system through transformers may be favorable or unfavorable; usually the effect is not large.

In a number of the cases investigated, it was found that the rectifiers were operating with unnecessarily large amounts of phase control at full load. As a result, the I·T product and voltage TIF were substantially higher than would normally be expected. In most of these cases, selection of different transformer taps and, occasionally, readjustment of the phase-control mechanism reduced the harmonics substantially.

In some installations, one or more of circuits *A*, *B*, or *C* may be missing and need not be considered in the classification procedure. For example, some installations are supplied from high voltage networks through transformer banks which supply power only to the rectifiers and the plants in which they are located; in such cases only the I·T into the high voltage network is of interest.

Illustrative Example

In order to illustrate the application of these methods, consider Figure 8.

Step 1. Figure 8A shows a schematic diagram of an assumed power system associated with a rectifier, and Figure 8B shows an impedance diagram on the rectifier transformer kilovolt-ampere base.

Assume that the exposures to *A*, *B*, and *C* are normal urban, miscellaneous joint use and roadway, and that power circuits *B* and *C* extend into residential areas.

The reactances in Figure 8B were determined as follows:

$$\%X_A = \frac{0.075 \times 1.5 \times 2{,}300}{13^2}$$

$$= 1.53\% \text{ (using equation 3)}$$

$$\%X_{T_1} = 8 \times \frac{2{,}300}{30{,}000}$$
$$= 0.62\% \text{ (using equation 4)}$$

$$\%X_{T_2} = 7 \times \frac{2{,}300}{20{,}000}$$
$$= 0.81\% \text{ (using equation 4)}$$

$$\%X_g = 10 \times \frac{2{,}300}{20{,}000}$$
$$= 1.15\% \text{ (using equation 4)}$$

$$\%X_g + \%X_{T_2} = 1.15 + 0.81 = 1.96\%$$

Reactance of T_1 and generator branch in parallel is

$$\frac{1}{\frac{1}{1.96} + \frac{1}{0.62}} = \frac{1}{0.51 + 1.61} = \frac{1}{2.12} = 0.47\%$$

The total commutating reactance on rectifier transformer kilovolt-ampere base:

$$\text{Total } \%X_c = 6.2 + 1.53 + 0.47 = 8.20\%$$

Step 2. The total I·T in feeder *A* is determined as follows:

With a total X_c of 8.2 per cent, the I·T per kilovolt-ampere on a 1-kv circuit is, from Figure 6, about 180. The total I·T in *A* is then:

$$\frac{180 \times 2{,}300}{13} = 32{,}000$$

From Table IV, the installation would be classified in category II from the standpoint of the direct feeder *A*.

Step 3. The per cent power source reactance used to estimate the voltage TIF on feeders *C* is the reactance of the generator branch and T_1 in parallel, which is 0.47%. From Figure 7, the voltage TIF per per cent source reactance is (for a total X_c of 8.2%) about 50. The voltage TIF impressed on *C* will thus be about $50 \times 0.47 = 24$.

From Table V, the installation would be classified in category I, from the standpoint of feeders *C*.

The per cent power source reactance used to estimate the voltage TIF impressed on *B* is $0.47 + X_A = 0.47 + 1.53 = 2.00\%$. Again, the voltage TIF per per cent is 50; the voltage TIF on *B* will then be about $50 \times 2.0 = 100$.

From the standpoint of circuit *B*, the installation will be (from Table V) in category II. If capacitors are to be used on the power system, it will be near the upper edge of category II. If circuit *B* should be used to supply a rural system, the installation would probably be in category III from the standpoint of the rural system.

Step 4. The total I·T on a 13-kv base going into the generator and high voltage network branches in parallel is (from step 2) 32,000. That going into the generators is of no interest. That going into the transmission network is

$$32{,}000 \times \frac{1.96}{1.96 + 0.62} = 24{,}000$$

On the 132-kv high voltage network, this I·T is reduced by the ratio of transformation of transformer T_1, or it is

$$24{,}000 \times \frac{13}{132} = 2{,}400$$

From Table VI, it will be seen that from the standpoint of the high voltage network, the installation is in category I.

Discussion of Example

From the analysis, it can be seen that the area in which problems are most likely to occur when the rectifier is placed in operation is that supplied by feeder *B*. It is possible that there will be some problems associated with feeder *A*, but unless the exposure extends practically the whole length of the feeder, they probably will not be unduly severe. The chances of problems associated with feeder *C* or with remote distribution systems fed from the 132-kv network are small.

It would seem wise in this case to examine the situation with regard to feeder *B* in more detail before placing the rectifiers in operation; for example, ascertain whether capacitors are used at widely separated points, the general degree of circuit balance, and the amount and type of exposure (particularly between the rectifier and the capacitors). Arrangements might be made for applying telephone cable sheath shielding in advance of the start of rectifier operation and for some method of emergency operation to take care on a temporary basis of any difficulties that might develop until permanent measures could be applied if tests indicated their necessity.

It probably also would be advisable, if practicable, to make tests on feeders *A* and *B* and on some telephone circuits exposed to them before the rectifier is brought up to full load, possibly during the preliminary tests of the rectifier.

Little, if any, attention need be given to the high voltage network or to feeders *C* except possibly to make a few tests after the rectifier is in regular operation to be sure that no unforeseen conditions exist.

It is of interest to note that in this case a ten per cent voltage reduction at full load by phase control would result in more than doubling the I·T's and voltage TIF's with a consequent substantial increase in likelihood of problems; for example, it would result in putting the installation well into category III from the standpoint of *B*, in category II from the standpoint of *C*, and close to category II from the standpoint of the high voltage network. (See example under "Installations Using Substantial Amounts of Phase Control.")

On the other hand, if the installation were 12 phase without phase control at full load, the I·T's and voltage TIF's would be reduced 35 per cent to 45 per cent, with a consequent substantial reduction in the likelihood of problems.

Small Rectifiers of Three or Four Phases

For small rectifier installations, the capacity may be less than that of 6 or 12 tubes of conventional size. For these cases it may be desirable to use four or eight rectifier tubes with a transformer connected in Scott/4-phase cross, or three tubes with a transformer connected in delta/3-phase zigzag. Estimates of harmonic effects of these connections may be based on the methods of analysis and the data given for 6-phase rectifiers, and increasing the I·T product and voltage TIF factors by the multipliers given in Table X.

Table X

Phase	Relative I·T and Voltage TIF Factors*
4	1.20
3	1.33

* These multiplying factors are to be applied to estimates based on 6-phase rectifiers.

Application to System of Other Than 60 Cycles

In order to apply the methods outlined here in cases where the power system frequency is other than 60 cycles, it will be necessary to obtain voltage TIF and I·T products from other sources.[1,5,9,17] With these factors known, installations can be classified as outlined in the foregoing.

Co-ordinative Measures

The solution of problems involving rectifiers where the application of co-ordinative measures is indicated is no different from other types of inductive co-ordination problems, in that close co-operation of all interested parties is necessary. Guiding principles and general practices are given in the report on "Principles and Practices for Inductive Co-ordi-

nation," by the Edison Electric Institute and the Bell Telephone System,[20] which recognizes that characteristics of both the power and the telephone systems must be taken into account. Of the various kinds of co-ordinative measures applicable to the power or telephone system, the following are the most important in connection with rectifier problems:

1. Advance planning of the method of supplying the rectifier from the standpoint of minimizing wave shape distortion.[23]

2. Phase multiplication of rectifier installation.[3,4,8,20]

3. Frequency selective devices.[21,23]

4. Reduction of power system unbalance to ground.[10,11,13,23]

5. Co-ordinated transpositions.[24] (Transpositions in power distribution circuits are of negligible value but may in some cases be useful in transmission circuits.)

6. Reduction of telephone system unbalance to ground.[10,11,13,23,26]

7. Shielding of telephone cable circuits.[25]

Some of these already have been referred to as factors in evaluating the likelihood of a given installation's causing trouble.

It is impracticable within the scope of this report to present a sufficiently detailed discussion of these measures to provide the information required for reaching a solution of a particular situation. However, the following general discussion of these measures, with some indication of their field of use, may be helpful in a more detailed examination of the material listed in the references.

Induction problems associated with rectifiers are most likely to involve exposures between power distribution circuits and telephone exchange circuits. The difficulties of applying and maintaining co-ordinative measures on a specific exposure basis, where power and telephone distribution circuits are involved, has led in recent years to relying more and more on the maintenance of the lowest practicable susceptiveness* of telephone circuits in general and of the smallest practicable wave shape distortion on power circuits in general. This is particularly true in rural areas where changes and extensions are frequent and where the power circuit influence is very greatly affected by wave shape.

Improved balance-to-ground of the newer types of telephone subscriber and central office equipment, which reached the stage of large-scale production just prior to the war, was most helpful in this connection. Another helpful factor in the prewar years was the increase in use of carrier on telephone toll circuits, which was accompanied by much more effective telephone transposition arrangements. Of great importance from the standpoint of power system influence was the development and application of the principle of phase multiplication, particularly in view of the tremendous expansion during the war in large scale rectifier installations.

Figures 6 and 7 have illustrated the effectiveness of phase multiplication in reducing the I·T and voltage TIF. This results from a reduction in the number of harmonic orders present as indicated in Table I. Another advantage of a relatively large number of phases is that power system resonance conditions tending to magnify the effects of harmonics are much less likely to occur at frequencies above the twenty-fifth harmonic (60-cycle base). Furthermore, if induction problems do arise, remedial measures are much less expensive than for a smaller number of phases because

1. The number of harmonics to be cared for is smaller.

2. The volt-ampere capacity of devices to reduce harmonics goes down rapidly as the lowest frequency which they must handle goes up.

The number of phases in an installation is, of course, limited to the number of anodes. To secure the greatest effectiveness of phase multiplication, the d-c loads on the individual rectifiers must be well balanced. Where they are not well balanced, shifting the phase of successive rectifier units to obtain phase multiplication will be much less effective. When one of the units in a multiphase installation is out of service, as for maintenance, the effectiveness of phase multiplication is reduced, but in only a small number of cases has this presented a problem of importance.

While phase multiplication is a powerful tool in the larger capacity installations, there are still many smaller installations of limited number of anodes where it cannot be employed. The only presently available method of controlling harmonics, other than phase multiplication, is some form of frequency selective device. Most of these devices have consisted of several resonant shunts or of a series reactor and shunt capacitor, per phase. The use of series reactors increases the voltage regulation of the rectifier unit which must be taken into account in many cases. Resonant shunts involve precision tuning and, where several shunts are used per phase, may involve special mounting arrangements.

With the more extensive use of power factor correction capacitors on power systems, a somewhat different approach to the frequency selective device design problem may, in some cases, be advantageous. This approach is first to consider what capacitor installations have been made or can be justified for power reasons and next to consider whether they will, or can be made to, produce harmonic control. For example, if a fairly large block of capacitors can be justified for power reasons at or near the rectifier location, they may be adequate alone, as has been the case in several large metallurgical rectifier installations, or coils to tune the entire bank broadly or to tune parts of the bank to particular frequencies might be added. The same thing might be done with capacitors at a supply substation bus if harmonic currents in the direct feeder are not important. In any such installations—whether equipped with tuning coils or not—the chances of adverse resonance at the lower harmonic frequencies need to be considered. In general, the reduction in I·T and voltage TIF would not be expected to be as large with the broadly tuned arrangement as with several sharply tuned resonant shunts, but in view of its very low cost (assuming the capacitors would be available, anyway), it may be advantageous in some cases, particularly where large reductions are not needed.

The extent to which other measures can be substituted in place of control of the rectifier harmonics in a specific case depends on many circumstances which cannot be described in detail here. However, a few of the more general considerations can be given, namely:

1. Situations where the effect of the rectifier is confined to the feeder between the source of supply and the rectifier offer the best field for the use of measures other than harmonic control, or a combination of these measures with a moderate degree of harmonic control.

2. In cases where the effect of the rectifier spreads beyond the feeder, but only to a limited extent, the same situation exists, although the advantage of reducing the harmonics is greater because of the greater uncertainties as to conditions in the future.

3. In cases where the effects spread over wide areas and involve numerous power distribution systems, it is almost hopeless to attempt to correct induction conditions without limiting the harmonics at the rectifier.

Installations Using Substantial Amounts of Phase Control

For installations employing substantial amounts of phase control at rated load,

* See Appendix I for explanation.

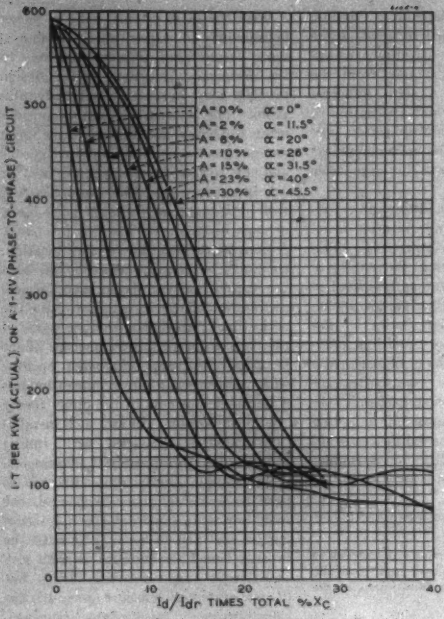

Figure 9. Six-phase rectifiers

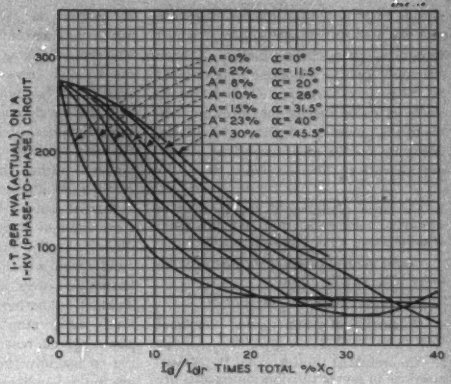

Figure 10. Twelve-phase rectifiers

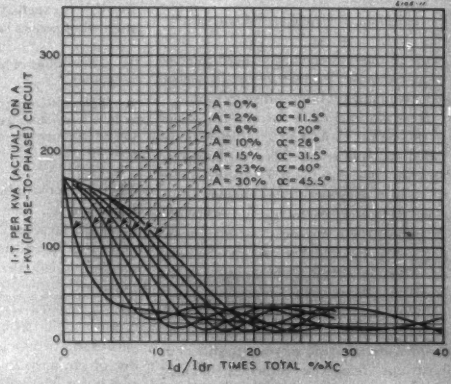

Figure 11. Twenty-four-phase rectifiers

Figures 9, 10, 11. I·T per kilovolt-ampere on 1-kv circuit for 6-, 12-, and 24-phase rectifiers with different amounts of phase control

For 60-cycle systems

I_d = actual d-c load current

I_{dr} = rated d-c load current

Total $\%X_c$ = per cent commutating reactance of rectifier transformer bank and supply system on rectifier transformer bank kilovolt-ampere base

α = phase control angle of retard

A = amount of phase control or per cent voltage reduction below output voltage with zero phase control ($A = 1 - \cos \alpha$)

To find I·T

1. Determine the value of I_d/I_{dr} times total $\%X_c$ for the particular load under consideration. Where the I·T for the rated capacity only is desired, total $\%X_c$ is used directly

2. From the curve for the appropriate number of phases and amount of phase control, determine the I·T per kilovolt-ampere

3. Multiply the I·T per kilovolt-ampere read on the curves by the *actual* kilovolt-ampere and divide by the phase-to-phase line voltage in kilovolts. This is the estimated phase I·T. Actual kilovolt-amperes can be obtained by multiplying rated kilovolt-amperes by the ratio I_d/I_{dr}

Figures 6 and 7 cannot be used to obtain I·T products and voltage TIF's. However, I·T products can be estimated from Figures 9, 10, and 11 which show I·T per rectifier kilovolt-ampere on a 1-kv line with various amounts of phase control, for 6-, 12-, and 24-phase installations, respectively, operating in a balanced manner. Voltage TIF can be estimated by using Figures 12, 13, and 14, which show voltage TIF per per cent power source reactance on rectifier transformer kilovolt-ampere base, with various amounts of phase control, for 6-, 12-, and 24-phase installations, respectively, operating in a balanced manner.

To illustrate the use of these curves, consider the example discussed under "Procedure in Classifying Proposed Installations" (see Figure 8), but assume ten per cent phase control at rated output voltage and current. The I·T product on the direct feeder A and the voltage TIF on B will be estimated:

1. The rectifier transformer kilovolt-amperes required for this rating will be (see equation 1)

$$1.15 \times \frac{(100+10)2{,}000}{100} = 2{,}530 \text{ kva}$$

2. The parallel reactance of the generator and T_1 on the rectifier transformer kilovolt-ampere base will be $0.47\ (2{,}530/2{,}300) = 0.52$ per cent (equation 4).

3. The line reactance (X_A) on rectifier transformer kilovolt-ampere base will be $1.53(2{,}530/2{,}300) = 1.7$ per cent.

4. The total $\%X_c = 0.52 + 1.7 + 6.2 = 8.4$ per cent.

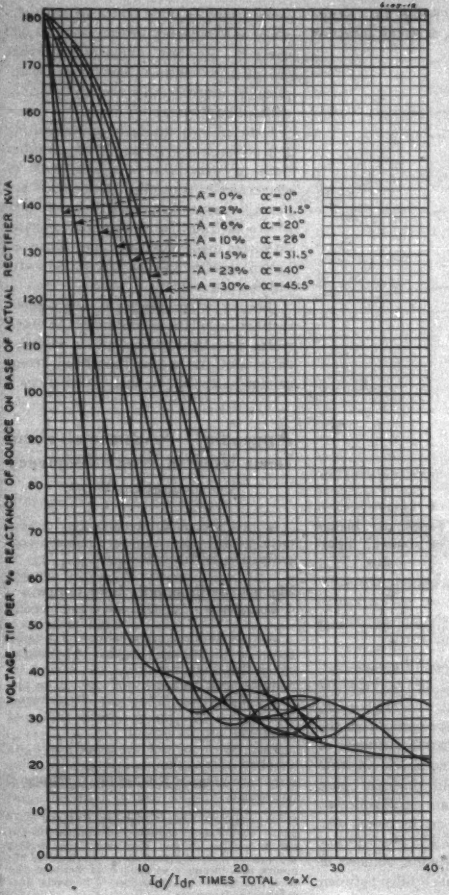
VOLTAGE TIF PER % REACTANCE OF SOURCE ON BASE OF ACTUAL RECTIFIER KVA
A = 0% α = 0°
A = 2% α = 11.5°
A = 6% α = 20°
A = 10% α = 26°
A = 15% α = 31.5°
A = 23% α = 40°
A = 30% α = 45.5°
Id/Idr TIMES TOTAL %Xc

Figure 12. Six-phase rectifiers

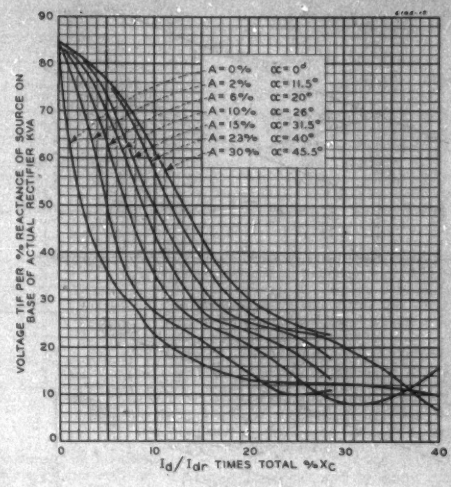
VOLTAGE TIF PER % REACTANCE OF SOURCE ON BASE OF ACTUAL RECTIFIER KVA
A = 0% α = 0°
A = 2% α = 11.5°
A = 6% α = 20°
A = 10% α = 26°
A = 15% α = 31.5°
A = 23% α = 40°
A = 30% α = 45.5°
Id/Idr TIMES TOTAL %Xc

Figure 13. Twelve-phase rectifiers

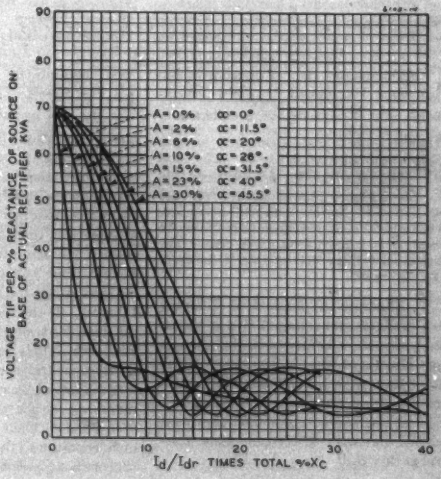
VOLTAGE TIF PER % REACTANCE OF SOURCE ON BASE OF ACTUAL RECTIFIER KVA
A = 0% α = 0°
A = 2% α = 11.5°
A = 6% α = 20°
A = 10% α = 26°
A = 15% α = 31.5°
A = 23% α = 40°
A = 30% α = 45.5°
Id/Idr TIMES TOTAL %Xc

Figure 14. Twenty-four-phase rectifiers

Figures 12, 13, 14. Voltage TIF per per cent reactance of power source for 6-, 12-, and 24-phase rectifiers with different amounts of phase control

For 60-cycle systems
I_d = actual d-c load current
I_{dr} = rated d-c load current
Total $\%X_c$ = per cent commutating reactance of rectifier transformer bank and supply system on rectifier transformer rated kilovolt-ampere base
α = phase control angle of retard
A = amount of phase control or per cent voltage reduction below output voltage with zero phase control ($A = 1 - \cos \alpha$)

To find voltage TIF:

1. Determine the value of I_d/I_{dr} times total $\%X_c$ for the particular load under consideration. Where the TIF for the rated capacity only is desired, total $\%X_c$ is used directly

2. Determine the per cent power source reactance on the base of *actual* rectifier kilovolt-amperes. For partial load, this can be found by multiplying source reactance on the base of rectifier transformer rated kilovolt-amperes by the ratio I_d/I_{dr}

3. From the curve for the appropriate number of phases and amount of phase control, determine the voltage TIF per per cent source reactance

4. Multiply the value read on the curves by source reactance found in step 2. This is the estimated voltage TIF

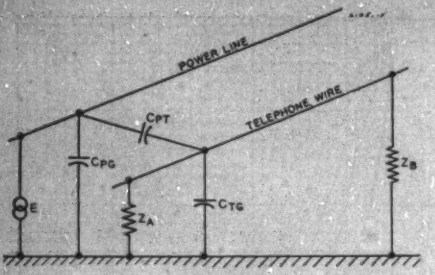

Figure 15. Nature of electric induction

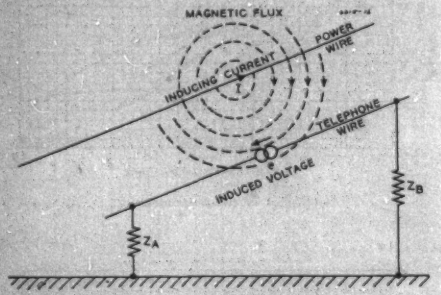

Figure 16. Nature of magnetic induction

5. From Figure 9, the I·T per kilovolt-ampere on a 1-kv circuit for total $\%X_c$ of 8.4 per cent, $\frac{I_d}{I_{dr}}$ /equal to one, and phase control of ten per cent, is about 410; or on a 13-kv circuit, it is 410/13=32. The total I·T on feeder *A* is then 32×2,530=80,000.

6. From Figure 12, the voltage TIF per per cent power source reactance is about 120. The total per cent power source reactance to point *B* is 0.52+1.7=2.2 per cent. The estimated voltage TIF at point *B* is, then, 120×2.2=260.

To illustrate the method of obtaining I·T products and voltage TIF's at partial load, suppose it is desired in the example just illustrated (that is, the same as Figure 8 but with a 2,530-kilovolt-ampere rectifier transformer) to find the conditions at a *current* output of 0.6 times rated output, but with 15 per cent phase control at this load. Proceed as follows:

1. $\frac{I_d}{I_{dr}} \times \%X_c = 0.6 \times 8.4 = 5.0$ per cent.

2. I·T per kilovolt-ampere on 1-kv circuit with 15 per cent phase control is (from Figure 9) about 530. On a 13-kv circuit, it would be 530/13=41. The kilovolt-ampere input can be taken as 2,530×0.6=1,520. The total I·T on the feeder is 1,520×41=62,000.

3. The voltage TIF per per cent power source reactance is (from Figure 12) about 163. To estimate voltage TIF at point *B* in Figure 8, multiply per cent power source reactance by 0.6; that is, 0.6×2.2=1.3. Next, multiply by 163, that is, voltage TIF at *B* equals 1.3×163=212.

Figures 10, 11, 13, and 14 assume balanced operation between the 6-phase units making up the 12- and 24-phase installations; that is, it is assumed that the d-c loads are equal, that the voltages of the d-c transformer windings on all units are identical, that the differences in phase control between units are small and that the harmonic voltages on the power supply system are too small to result in unbalances. If the d-c winding voltages of the rectifier transformers differ between units (which may be caused by operation on different transformer taps) and different amounts of phase control are used, the curves no longer give accurate results, even if the d-c loads are balanced. Under such conditions, the suppression of the "normally suppressed" harmonics is likely to be impaired and partial suppression of "normally unsuppressed" harmonics may occur.

Other Forms of Conversion Equipment

Co-operative investigations have been made in connection with two installations of large frequency changers connecting 60-cycle and 25-cycle 3-phase systems.[11,12] Tests have also been made on two installations of equipment for converting from 3-phase 60 cycles to single-phase at a frequency on the order of 1,000 cycles.[12] The test results indicate that the methods outlined herein can be applied in connection with such installations without large error.

Data are not available for estimating I·T products and voltage TIF's for other forms of conversion apparatus, such as electronically controlled motors. It appears, however, that where the power supply to such devices is balanced 3-phase, estimates made along the lines discussed herein would provide at least a good starting point in studies.

The inductive effects of single-phase rectifier installations are subject to much wider variations than 3-phase installations, and the methods outlined herein cannot be applied to such installations.

Appendix I. Fundamentals of and Terms Used in Noise Frequency Co-ordination Work

In this appendix, fundamentals of and terms used in noise frequency inductive co-ordination work are discussed.

Electric and Magnetic Induction—Coupling

Voltages induced on telephone circuits by power circuit voltages are said to be caused by electric induction; voltages caused by power circuit currents are said to be the result of magnetic induction. These forms of induction exist independently and must be so treated.

The process of electric induction in its simplest form is shown in Figure 15. The power wire has on it a harmonic voltage *E* to ground.

1. Between the power wire and a nearby telephone wire, electric coupling, represented by capacitance C_{PT}, exists. The magnitude of this capacitance is directly proportional to length of exposure and increases as separation between the wires decreases. Its impedance is inversely proportional to frequency.

2. The telephone wire has finite impedances to ground, Z_A and Z_B, outside the exposure. These impedances are usually much smaller than the impedance of C_{PT}. The current to the telephone wire is therefore controlled by C_{PT}; it is directly proportional to the coupling and to frequency and magnitude of *E*. The voltage on the telephone wire is the current through C_{PT} times Z_A and Z_B in parallel; it is roughly proportional to coupling and frequency.

The magnetic induction process in its simplest form is shown in Figure 16.

1. A mutual reactance, or magnetic coupling, exists between the power wire and the nearby telephone wire by virtue of the fact that the magnetic flux associated with the power wire current links the telephone wire. The total amount of flux (per unit of power wire current) which links the telephone wire is proportional to length of exposure and increases as separation is decreased.

2. The voltage *e* induced along the telephone wire is proportional to the total flux which links it and is also proportional to frequency. The current in the telephone wire is this voltage divided by (Z_A+Z_B). The voltage to ground at one end of the exposure is this current times Z_A; at the other, times Z_B.

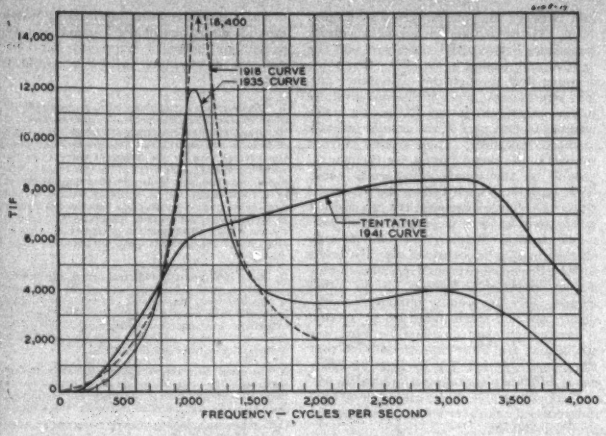

Figure 17. TIF weightings

Voltage TIF and I·T Products

The frequencies in human speech range from the order of 125 cycles to upwards of 10,000 cycles per second. A much narrower band of frequencies is sufficient to carry on a satisfactory conversation and most telephone circuits are designed to transmit such a narrower band.

Each harmonic voltage or current in a power system induces a voltage of the same frequency in a paralleling telephone circuit which, in turn, may actuate a telephone receiver and cause an audible sound. The composite of the sounds of all such frequencies present usually results in a humming sound commonly called noise. Different frequencies in this noise have different interfering effects[27, 29] depending on the characteristics of the telephone circuits, receiver, the human ear, and other factors; relative interfering effects are called noise weightings and have been ascertained by extensive tests. The composite of the noise voltages in the circuit can be measured by means of a noise measuring set which contains networks having frequency-transmission characteristics in accordance with the noise weightings, and a meter which adds components as the square root of the sum of the squares.

Since the effects of both electric and magnetic coupling are directly proportional to frequency, the relative noise influence of voltages and currents on the power system is proportional to the product of noise weighting and frequency. For any frequency, this product (times a constant) is known as TIF (telephone influence factor) weighting. TIF weighting curves as functions of frequency are shown in Figure 17.

There are three different sets of TIF weightings which reflect changes in transmission-frequency characteristics of telephone circuits and instruments over a long period, namely:

1. The "1918" weightings. These were known as telephone interference factor weightings, and this name is still used to distinguish them from the later weightings which are called telephone influence factor weightings.
2. The "1935" weightings.[30]
3. The tentative "1941" weightings. These weightings have not been standardized yet.

The very small weightings of 60 cycles explains why, from the noise frequency induction standpoint, only the harmonics are of interest.

While much induction work is carried on on the basis of individual harmonics, it frequently is desirable to use an over-all measure of the influence of a current or a voltage in a power circuit. This over-all measure is obtained by multiplying the magnitude of each harmonic present (amperes, for current; kilovolts for voltage) by its TIF weighting, and taking the square root of the sum of the squares of these products. The result is, for current, I·T product; for voltage, KV·T product. These products can be measured directly by the use of a noise measuring set and a TIF coupler, the latter having a transmission-frequency characteristic directly proportional to frequency. So-called TIF meters also can be used.

Balanced, Residual, and Ground Return Currents and Voltages

Suppose in Figure 16 there were another power wire very close to the one shown there and that it carried a current equal and opposite to the current in the original wire; such a set of currents would be called balanced. The flux cutting the telephone wire then would be only the difference between the fluxes at that point arising from the currents in the two power wires. If the separation between the power wires were small, this difference would be small and hence the coupling would be small as compared to that for current which goes out on one or more wires and returns through the earth, that is, ground return current.

A similar analysis with respect to voltages would indicate the same conclusions.

For a power circuit of any number of phases and wires, the following terms apply:

1. Ground return current is the vector sum of the

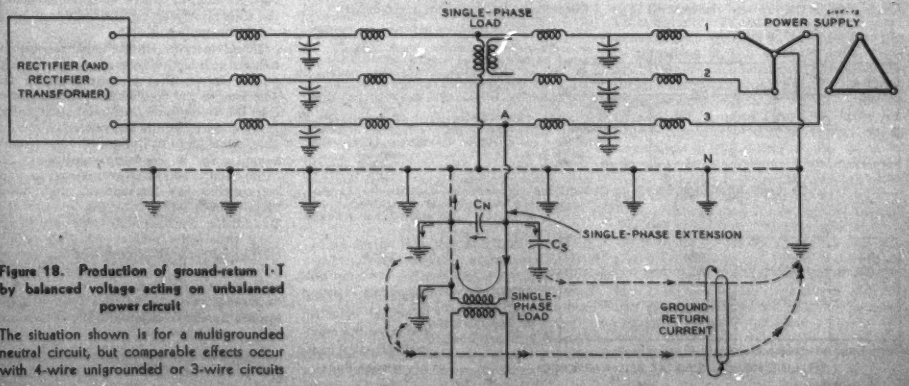

Figure 18. Production of ground-return I·T by balanced voltage acting on unbalanced power circuit

The situation shown is for a multigrounded neutral circuit, but comparable effects occur with 4-wire unigrounded or 3-wire circuits

actual currents in all the wires of the circuit.

2. Residual current is the vector sum of the actual currents in the phase wires. In a 3-phase 3-wire circuit, residual and ground return currents are the same. In a 4-wire 3-phase circuit, part of this residual current may stay in the neutral wire, and the influence of this part is about the same as if it were balanced. In a 2-wire circuit consisting of an extension of a phase wire and neutral of a 3-phase 4-wire circuit, phase and residual current are the same; part of this residual current is ground return.

3. Balanced currents are those components of the actual phase currents whose vector sum is zero.

4. Residual voltage is the vector sum of the voltages between phase wires and earth.

5. Balanced voltages are those components of the actual phase-to-ground voltages whose vector sum is zero.

The over-all influence of any one of these components is measured by its I·T or KV·T product. For distribution circuits, and in many cases for transmission circuits, over-all influence is controlled by ground return I·T, or residual KV·T. In dealing with voltages of known magnitude, voltage TIF is frequently used instead of KV·T; it is KV·T divided by voltage in kilovolts. For residual voltages on 3-phase generators, residual component voltage TIF is sometimes used; it is one third residual KV·T divided by phase-to-neutral voltage.

In a 3-phase circuit with no single-phase extensions or loads, the ground return I·T and the residual KV·T are usually small except for triple harmonics (third and odd multiples thereof). If, however, there are single-phase taps or loads, ground return harmonic currents can occur even though the harmonic voltages are impressed in a perfectly balanced manner, as by a rectifier. The conditions leading to this effect are shown in Figure 18. Here is shown a feeder from a power source to a rectifier; there is a single-phase extension. For simplicity in explanation, a multigrounded neutral circuit is shown; comparable effects may occur with unigrounded neutral or 3-wire circuits as explained later.

As explained in "Nature of Problem" in the main body of this report, the harmonic currents produced by the rectifier load flow through the phase wire reactances and produce harmonic voltages. The harmonic voltage-to-neutral thus caused at point *A* in Figure 18 is impressed on the single-phase tap. Capacitance exists between the phase wire in the tap and the neutral (C_N) and between the phase wire and ground (C_g). The load likewise presents a finite impedance between the phase wire and the neutral and ground in parallel. Harmonic currents flow through the capacitance and load impedances. Part of this current flows in the neutral wire (about 40 per cent in the usual case) and part in the ground (usually about 60 per cent). The ground current returns to the power circuit via the neutral ground on the supply transformer bank. Thus on the tap itself and on the portion of the 3-phase circuit between the tap and the power source, there is ground return harmonic current. Harmonic currents through single-phase loads connected directly to the 3-phase line produce ground return harmonic current in a similar fashion. In an actual circuit, there are usually numerous single-phase taps and single-phase loads; ground return current can circulate between one tap or load and other taps or loads, so that the ground return I·T is likely to be different at different places along a 3-phase circuit.

That comparable effects can occur on long unigrounded neutral or 3-wire circuits can be shown as follows:

1. Consider first a 4-wire unigrounded neutral circuit with a single-phase tap. Imagine that, in Figure 18, all grounds on the neutral are removed except the one at the power supply bank and series inductances and shunt capacitance are distributed along the neutral as well as the phase wires. Harmonic current can still flow through the capacitance between the phase wire and ground; this current is ground return. Furthermore, under some conditions, substantial voltages to ground can exist on the neutral at harmonic frequencies; they may cause harmonic currents through the neutral-to-ground capacitance, and these currents are ground return.

2. On a 3-wire circuit, the single-phase tap would be connected to two of the phase wires. Harmonic currents can flow through the capacitances to ground from both phase wires and become ground return. Even if there is no neutral-to-ground connection at the power supply bank, these ground return currents can exist; they return to the system through the capacitance to ground of the remaining phase wire in other parts of the system.

As a general rule, overhead urban distribution systems are so short that the capacitances can be neglected. Ground return current can occur in such systems only if the neutral is multigrounded. Rural systems, however, are usually long enough so that the harmonic currents through the capacitance are frequently controlling; substantial ground return I·T can occur regardless of whether or not a neutral wire is present or where or how the system is grounded.

There are three other methods by which ground return harmonic current can be caused by balanced impressed harmonic voltages or currents (as by a rectifier), namely:

1. The currents in the phase wires magnetically induce voltages along the neutral or ground wire. If the phase wires are not disposed symmetrically with respect to the neutral, the voltages induced along the neutral wire by the balanced currents in the three individual phase wires will not be equal. The vector sum can, in a multigrounded neutral circuit or a transmission circuit equipped with a ground wire, cause current to circulate between the neutral or ground wire and ground; this current is ground return. This effect usually is important only in cases where the circuit is very well balanced otherwise.

2. On a multigrounded neutral urban circuit with capacitors, small differences between the reactances of the individual phase wires can cause substantial ground return harmonic current if the capacitors and circuit are very close to resonance at one of the harmonic voltages present. This phenomenon is discussed more fully in Appendix II.

3. In some cases the minor differences in the reactances of the phase wires can cause ground return harmonic currents even in the absence of capacitors. Such ground return currents can occur only when

(*a*). The circuit is long enough to permit appreciable currents through the natural capacitances, *or*

(*b*). There are two or more transformer bank neutral-to-ground connections between which the ground return current can circulate.

Metallic and Longitudinal Telephone Voltages and Currents—Susceptiveness

Assume that in Figure 16 another telephone wire is added parallel and close to the first. The second wire will be linked by nearly the same flux as the first, and the difference in the voltages along the two wires will be a small fraction of that along either one. If these two wires are used as a metallic telephone circuit, the noise voltage acting around this circuit will be a small proportion of that which would act in a telephone circuit consisting of one wire with ground return, that is, a ground return circuit.

The same analysis could be carried through for electric induction with the same conclusions.

Thus in a metallic telephone circuit, there is longitudinal circuit induction which is the voltage along or to ground on the conductors in parallel, and direct metallic circuit induction, which is the difference between the voltages along or to ground on the two wires, the direct metallic circuit induction being much the smaller.

Direct metallic circuit induction can be reduced still further by transposing the telephone circuit, that is, interchanging the positions of the conductors periodically so that the voltages on both tend to be equal. In open wire circuits the reduction obtainable, while large, is limited by unavoidable irregularities in exposure conditions. In cable circuits the pairs are twisted so as to be continuously transposed, and direct metallic circuit induction can be neglected. In addition, the telephone cable sheath provides practically perfect shielding against electric induction if grounded at one or more points, and it provides some shielding against magnetic induction if grounded at both ends, the degree of shielding being limited by the resistance of the sheath and of the grounds.

Longitudinal circuit induction can cause noise in a metallic circuit by acting on tele-

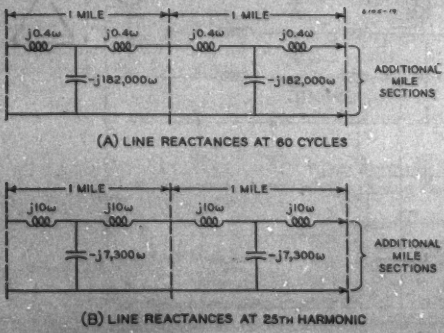

Figure 19. Phase-to-neutral inductive and capacitive reactances of typical transmission line

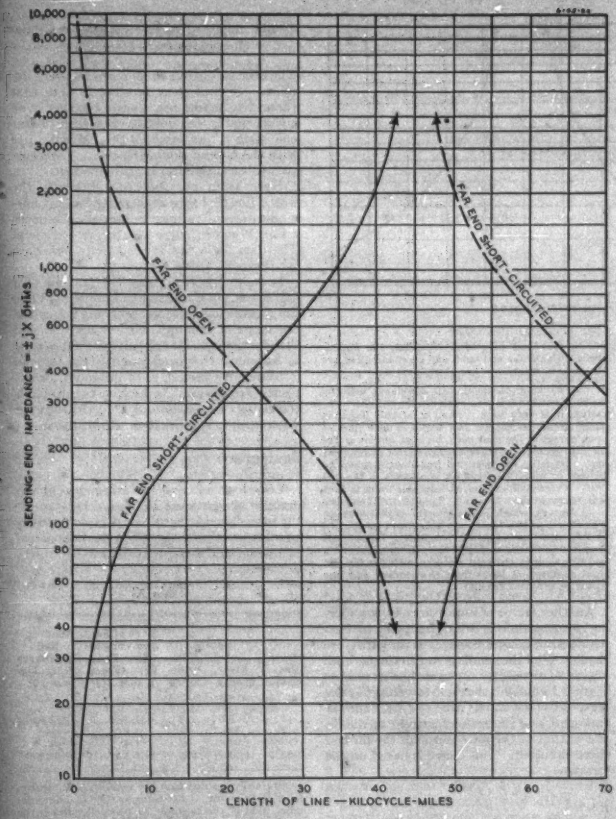

Figure 20. Sending-end phase-to-neutral impedance of typical transmission line with far end open and short-circuited

——— Sending-end inductive reactance $= +jX$

– – – – – Sending-end capacitive reactance $= -jX$

Impedances are for condition of no losses in circuit. For effect of losses, see text

phone circuit unbalances. These unbalances are of two types:

1. Series impedance unbalances, that is, differences in the impedances of the two wires of the circuit.

2. Shunt admittance unbalances, that is, differences in the admittances between the two wires of the circuit and ground.

Unbalances can occur in line, station, or central office equipment. Typical types of unbalances in these three locations are:

1. Lines. Series unbalances may be caused by imperfect joints or by variations in cross section or composition of the two conductors of a circuit. Shunt unbalances may be caused by such things as missing insulators, foliage touching the wires, transposition irregularities, and unbalances in capacitance to ground in cables.

2. Stations. Shunt unbalances only need to be considered. The principal unbalance is the ringer-to-ground connection used for party-line ringing. Its magnitude depends on the impedance of the ringer and the details of the subset connections.

3. Central office. Series unbalances can occur on account of unbalances in relays used for supervision, differences in capacitance of condensers used to block direct current paths, and so forth. Shunt unbalances may be caused by differences in the inductances of relay, retard or repeating coil windings connected between the wires and ground, differences in the capacitances to ground of wires, repeating coil windings, and other factors.

The degree to which a telephone circuit can be affected by given extraneous electric and magnetic fields is called its susceptiveness. Susceptiveness depends on such things as balance and adequacy of transpositions, and on the frequency response of the circuits and instruments and the level (magnitude) of the telephonic current and voltages at the point where the exposure exists.

Inductive Co-ordination

It is theoretically possible to have power circuits with practically zero influence (for example, by having no harmonics), they would not cause noise in any telephone circuit regardless of its susceptiveness. It is theoretically possible to have telephone circuits of practically zero susceptiveness (for example, by having perfect balance and transpositions); they would not be noisy regardless of the influence of nearby power circuits. Also, of course, if the power and telephone systems were separated by large distances, the coupling, and hence the noise, would be negligible. None of these methods is practicable, in general, in the present state of the art. The practical job of noise frequency inductive co-ordination consists of so controlling coupling, influence, and susceptiveness within practical limits that telephone circuit noise is controlled adequately at minimum cost and maximum satisfaction to both power and telephone customers.

Appendix II. Propagation of Harmonic Currents and Voltages

Line Characteristics

For short feeders between a source of power supply (generator or substation) and a rectifier installation, only the inductive reactances need be considered in estimating harmonic voltages and currents. But for longer circuits such as transmission or rural distribution circuits, the capacitances between the different wires and between the wires and ground must be taken into account when dealing with harmonic frequencies.

Why the capacitances associated with the wires have a greater effect at harmonic frequencies than at 60 cycles can be shown by considering the constants of a typical transmission line as illustrated in Figure 19. Here are shown the series inductive reactances and shunt capacitive reactances on a phase-to-neutral basis for such a line (Figure 19A) at 60 cycles and (Figure 19B) at the twenty-fifth harmonic. It can be seen that at 60 cycles the shunt capacitive reactances are very large compared with the series inductive reactances; a line of short or moderate length can be considered simply as consisting of $j0.8$ ohm per mile. But at the twenty-fifth harmonic, the series impedances are increased 25 to 1, and the shunt impedances are decreased 25 to 1. At the twenty-fifth harmonic, the total series impedance becomes as large as the total shunt impedance in 19.1 miles of line (that is, $19.1 \times 20 = 382 = 7{,}300/19.1$), whereas in the case of 60 cycles, this equality does not occur until the line is about 480 miles long.

To obtain an idea of how, quantitatively, this difference affects line performance, consider Figure 20, which shows the sending-end impedance of a typical transmission line with the far end open and with it short-circuited, as a function of length and frequency, neglecting losses. These curves are computed from the formulas:

Sending-end impedance with far end open $= -jZ_o \cot \theta$

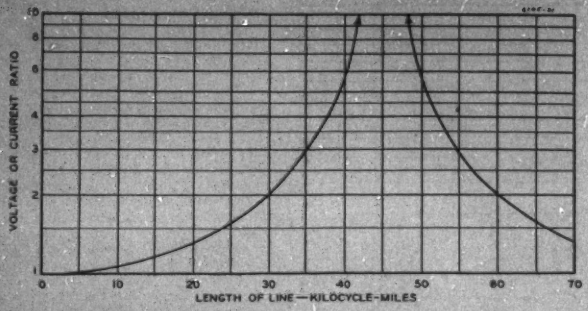

Figure 21. Ratio of current at far end to current at near end with far end short-circuited and ratio of voltage at far end to voltage at near end with far end open

Ratios are for condition of no losses in circuit. For effect of losses, see text

Sending-end impedance with far end short-circuited $= jZ_o \tan \theta$

where

Z_o = characteristic impedance to neutral (380 ohms in the example)

θ = line angle (or phase shift) in degrees = frequency times length times 360 divided by velocity of propagation

Since, in a smooth circuit without losses (a good approximation for power transmission circuits at harmonic frequencies), the velocity is independent of frequency, the curves can be plotted using length times frequency, that is, kilocycle-miles, as abscissas.* For example, a 100-mile line at 60 cycles is 0.06 kilocycle times 100 miles = 6 kilocycle-miles; a 20-mile line at 1,500 cycles is 30 kilocycle-miles, and so forth. For such lines the velocity is about 180,000 miles per second.

With a velocity of 180,000 miles per second, θ, or phase shift, is two degrees per mile per kilocycle, which can be derived as follows:

$$\text{Wave length at frequency } f = \frac{180{,}000 \text{ miles}}{f}$$

Wave length = 360 degrees

$$\text{Whence } \frac{180{,}000}{f} \text{ miles} = 360 \text{ degrees}$$

$$\text{Degrees per mile} = \frac{360f}{180{,}000} = 2° \times \frac{f}{1{,}000}$$

If f is in kilocycles, degrees per mile = two degrees times f (in kilocycles).

It will be noted from Figure 20 that

1. With the far end open, the impedance looking into the near end is capacitive reactance up to 45 kilocycle-miles; with the far end short-circuited, it is inductive reactance up to that length. Above 45 kilocycle-miles, the signs are reversed.

2. At 22.5 and 67.5 kilocycle-miles, the impedances with the far end open and short-circuited are the same in magnitude but opposite in sign.

3. At 45 kilocycle-miles, the impedance with the far end open is very low; with the far end short-circuited, it is very high. That is, at this length a short circuit on the far end tends to look like an open circuit at the near end; an open circuit at the far end tends to look like a short circuit at the near end. Actually, the near end impedances would go to zero or infinity except for the losses in the circuit. The significance of 45 kilocycle-miles is that it is "quarter wave length." That is, 45 × 2 degrees = 90 degrees, which is one quarter of 360 degrees. The effects at this length are sometimes referred to as "natural line resonance" because a line of this length with the far end open looks from the sending end like a series resonant circuit; with the far end short-circuited, it looks from the sending end like a parallel resonant circuit.

* That frequency and length can be combined is also obvious from the fact that the inductive reactance as well as the capacitive admittance (reciprocal of reactance) are directly proportional to length and frequency.

Another factor of importance in considering propagation is what happens to harmonic currents and voltages as they traverse the line from the sending-end to the far end. Figure 21 shows, for the same line as used in Figures 19 and 20, the ratio of voltage at the far end to that at the near end with the far end open, and the ratio of current at the far end to that at the near end with the far end short-circuited. This curve is based on the formula

$$R = \frac{1}{\cos \theta}$$

where

R = ratio of voltage at far end to that at near end with far end open, or ratio of current at far end to that at near end with far end short-circuited.

θ = line angle in degrees = two degrees times kilocycle-miles.

The abscissas are again in terms of kilocycle-miles. It is of some interest to note that these two ratios are shown by the same curve, that is, the voltage ratio with the far end open is the same as the current ratio with the far end short-circuited. The quarter wave length effect is again evident.

Here again the difference between the way a line performs at 60 cycles and at harmonic frequency may be noted. Consider a line 50 miles long with the far end open. The data for a few typical frequencies are set down in Table XI.

In most practical cases the far end of a line is not open nor short-circuited. While the treatment of the general case is beyond the scope of this appendix, it may be said that for transmission circuits the impedance at harmonic frequencies across the far end is frequently almost pure inductive or capacitive reactance. In such cases the effects shown in Figures 20 and 21 occur, but for different line lengths than shown there.

Equipment

Transformers and rotating machinery present almost pure inductive reactances; the impedance at harmonic n is very closely equal to n times the 60-cycle impedance

Table XI

Harmonic	Frequency	Kilocycle-Miles	Ratio of Far End Volts to Near End Volts (From Figure 21)	Sending-End Impedance (From Figure 20)
1	60	3	1.006	$-j3{,}850$
7	420	21	1.35	$-j425$
17	1,020	51	4.8	$+j84$
25	1,500	75	1.15*	$+j660$**

* Obtained from fact that the ratio for L kilocycle-miles is the same as the ratio for $(90\text{-}L)$ kilocycle-miles, that is, the ratio for 75 kilocycle-miles is the same as the ratio for 15 kilocycle-miles.

** Obtained from the fact that sending-end impedance with far end open of a line L kilocycle-miles long is the same as sending-end impedance with far end short-circuited of line $(L\text{-}45)$ kilocycle-miles long, that is, sending-end impedance with far end open of line 75 kilocycle-miles long is the same as impedance with far end short-circuited of line 30 kilocycle-miles long.

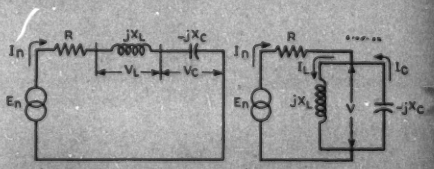

Figure 22. Series and parallel resonance

For series resonance,

$$I_n = \frac{E_n}{R + jX_L - jX_C}$$

If $X_L = X_C$, then

$I_n = E_n/R$

$V_L = I_n X_L$

and

$V_C = I_n X_C$

For parallel resonance,

$$I_n = \frac{E_n}{R + \frac{(jX_L)(-jX_C)}{jX_L - jX_C}}$$

If $X_L = X_C$, then

$$I_n = \frac{E_n}{R + \frac{X_L X_C}{0}} = 0$$

$V = E_n$

$I_L = V/jX_L = E_n/jX_L$

and

$I_C = V/-jX_C = E_n/-jX_C$

A capacitor presents practically pure capacitive reactance of a magnitude equal to its 60-cycle reactance divided by n. For generators and synchronous motors, the average of the negative sequence and subtransient 60-cycle reactances is used in estimating harmonic reactance.

Transformers step up or step down impedances by the square of the turn ratio; that is, if an impedance Z is connected to the low side of a transformer having a voltage ratio K, it appears when looking through the transformer from the high side as ZK^2. Where transformers are used, the impedances of equipment on one side can be transferred to the other either by computing them as if they were actually operated on the desired voltage base or by computing them on their own voltage base and multiplying by the square of the transformer ratio.

Resonance Between Equipment and Lines

It has been noted in Figure 20 that over comparatively wide ranges of frequency times length, the sending-end impedance of lines is capacitive reactance. Since the reactance of transformers and rotating machinery is inductive, it is not uncommon to find a frequency at which the reactances of the apparatus and the line are equal and opposite.

When equal and opposite reactances are connected together, a condition known as "resonance" occurs. Two variations of resonance can be recognized, that is, series resonance and parallel resonance, as illustrated in Figure 22. There it is shown that:

1. For series resonance, the current through and the voltages across the inductive and capacitive reactances are limited only by the resistance in the circuit. Thus, in a low loss series resonant circuit, large voltages and currents can occur even with relatively low impressed voltage.

2. For parallel resonance, the current in the reactive elements is equal to the impressed voltage divided by the reactance of the element. The voltage across the circuit does not exceed the internal voltage of the source. Consequently, large currents can occur only when the internal voltage of the source is high or the reactances of the elements are low. On the other hand, the current through and the voltage across the reactive elements are relatively unaffected by the internal resistance of the source.

In Figure 23 are shown examples of possible resonance conditions which may be set up at a harmonic frequency between the inductive reactance of equipment and the capacitive sending-end reactance of lines. It is assumed that the source is putting out a harmonic of the resonant frequency.

Rotating machinery and transformers usually have low internal resistance so that substantial increases in harmonic voltages and currents at particular frequencies can be caused by either of the types of situation illustrated. Transmission lines with harmonics put on at remote points usually also act as sources with low internal resistance when considering harmonics impressed on distribution systems. This is because

1. The impedance looking into a transmission line, to which most of the apparatus connected has inductive reactance, usually has a relatively small resistive component.

2. Further, the resistive component (as well as the reactive component) is stepped down by the square of the transformer ratio when considered on the distribution circuit voltage base.

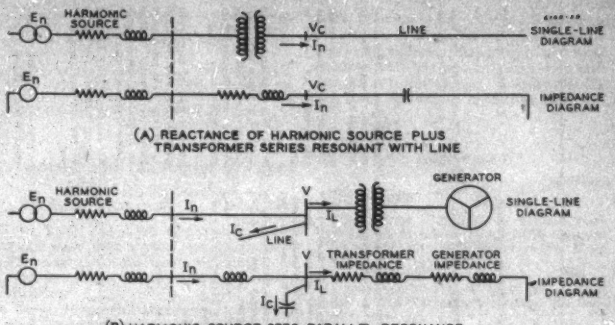

Figure 23. Examples of resonance between equipment and lines

On the other hand, the internal resistance of a rectifier, considered as a source of harmonics, is significant; the resistance is an inverse function of the load. Therefore, except for the larger rectifier installations, which are characterized by low internal resistance, large increases in harmonic currents or voltages at the sending ends of lines because of resonance are likely to occur only in cases of parallel resonance (as in Figure 23B).

Fortunately, most of the resonances encountered in practice are relatively sharp, and there is usually no harmonic present of exactly the resonant frequency. Consequently, the increases in harmonic voltage and current because of resonance are only moderate in most cases, although in rare cases these increases may be ten or more to one.

The ratios of harmonic currents and voltages at the two ends of a line (shown in Figure 21) are independent of whether the magnitudes at the sending end are affected by resonance.

Rural Distribution Circuits

Propagation of harmonics over rural distribution circuits differs from that over transmission circuits in two important respects:

1. The impedance presented by load is largely resistive in series with inductive reactance, the latter being caused by the load transformers. At night, and sometimes during the day, the load is light and the line operates essentially with the far end open.

2. A large proportion of the line mileage is likely to be single-phase, so that the ratio of ground-return harmonic current to phase harmonic current is much higher than for a transmission line. For single-phase multigrounded neutral rural lines, the ratio of ground return to phase harmonic current is on the order of 0.6; for unigrounded neutral or delta lines, the ratio is variable and it may be as high as unity.

Because of the facts that over subatantial periods, rural power lines act as if they were open and that the line length is moderate, the sending-end impedance is likely to be capacitive reactance at the frequencies of the important harmonics. The sizes of transformers used to supply rural lines are frequently such that resonance occurs somewhere between the fifth and twenty-fifth harmonics. During heavier load periods, this resonance is considerably damped by the load; as a result, the noise influence of a rural power circuit usually is substantially higher at night than during the periods when the load is heavier.

In dealing with the single-phase branches of distribution circuits, it is rather common to use impedance-to-ground instead of impedance-to-neutral. Impedance-to-ground is phase-to-ground voltage divided by ground-return current or, conversely, ground-return current is phase-to-ground voltage divided by impedance-to-ground. Figures 20 and 21 can be used to obtain an idea of what happens on a single-phase rural line with the far end open or short-circuited when a harmonic voltage is impressed on it by making the following changes:

1. Before using the curves, multiply the actual kilocycle-miles by the following factors to take account of the lower velocity of propagation:

Unigrounded neutral	1.3
Multigrounded neutral	1.1

2. Multiply the ordinates in Figure 20 by about two. The ordinates in Figure 21 are unchanged.

There are many factors affecting the influence of a rural power line which cannot be discussed here. References 11, 12, and 23 discuss these matters in detail.

Urban Distribution Systems

Overhead urban distribution systems are usually so short that the effect of capacitance can be neglected except possibly for unusually long lightly loaded circuits with unusually high impressed magnitudes of the higher frequency harmonics. Consequently, in the absence of capacitors, the only path for harmonic currents is through the loads. Unlike rural distribution circuits, ground-return harmonic current can flow only where the neutral is multigrounded.

Where capacitors are used, they frequently present lower impedances at harmonic frequencies than do the loads. It not infrequently occurs that the resonant frequency of the capacitors and supply transformers and line is between the fifth and about the eleventh harmonic. In some cases this results in relatively large harmonic currents and voltages at one of these frequencies. In some cases the small differences between series reactances of the three

Table XII. Summary of Studies Made in a Few Selected Cases of Rectifier Installations

Case	Size, Kilowatts	Number of Phases	Feeder A of Figure 5	Part B of Figure 5	Part C of Figure 5	Supply Transformer D, Figure 5	Supply System N, Figure 5	I·T* In A	I·T* In N	Voltage TIF* On B	Voltage TIF* On C	Co-ordination Problems	Remarks
A	21,600 +5,400	12 6	—	—	—	—	Extensive 154 and 120 kv	—	32,000 on 120 kv	—	—	Extensive over several states	Changed to 30-phase with condition as indicated in example A[1]
A[1]	27,000	30	—	—	—	—	Extensive 154 and 120 kv	—	2,600 on 120 kv	—	—	None	—
B	41,000 +20,500	48 24	—	13-kv feeding distribution	—	75,000 kva	Extensive 115 and 230 kv	—	11,000 on 115 kv	50(E)	—	Moderately extensive without capacitors connected	Large capacitor bank for power purposes reduced effect to negligible value
C	114,800	24 36 48	—	—	—	—	Extensive 230, 69, and 115 kv	—	11,000 on 230 kv	—	—	Not very extensive because of particular layout of power system. Potentially important if power interconnections changed	Tentative plans made to change 24-phase to 48-phase. Action depends on future of plant
D	32,500	36	—	—	—	36,000 kva	110 kv	—	5,000	—	—	Severe caused primarily by quarter wave length power line at 1,020 cycles, particularly when one 6-phase rectifier unit shut down	Change in power layout and removal of minor irregularities in the rectifier phase shifting arrangements corrected condition
E	2,000	6	13-kv cable direct to generator bus	Urban distribution	—	—	Generating station, 13- and 26-kv cables feeding urban and suburban distribution	42,000	42,000	60	20**	A few	Resonance between cables and generator at 1,020 and 1,140 cycles resulted in substantial increase in influence. Change to 12-phase operation practically eliminated effect
F	1,000	12	13 kv, overhead	Urban distribution	None	None	Metropolitan cable and open-wire network	17,000	17,000	85–125 Value depends on method of feed	—	Fairly extensive to parts A and B only	Filter installed which reduced voltage TIF and I·T about 4.5 to 1 and eliminated problem
G	1,000	12	13 kv, overhead	None	None	None	Metropolitan cable and open-wire network	19,000	19,000	—	—	None	No problem because of absence of parts B and C
H	3,000	6	12-kv cable	—	—	—	Extensive urban cable network	60,000(E)	60,000(E)	—	—	No a-c problem. Filter required on d-c side	Substantial exposure of telephone cable circuits to d-c feeders and trolleys resulted in telephone noise problem
I	200	6	8 miles, 13 kv, semirural	40 miles, 13 kv, semirural	—	—	Extensive high-voltage network	2,300	Negligible	100(E)	—	Extensive because of part B	Filter installed; reduced voltage TIF and I·T about 5 to 1. Power factor improvement provided by filter turned out to be valuable
J	1,300	6	—	—	—	—	Fairly extensive 33 kv	—	5,000	—	—	Severe over about 600 square miles	Filter applied which eliminated problem
K	600	6	6.9 kv, industrial	6.9 kv, industrial and suburban	6.9 kv, industrial and suburban	—	25-kv heavy industrial	24,000–16,000(E)***	6,000–4,000(E)***	120–335***	20–50***	Little or none	Appears to be some likelihood of problems if power or telephone conditions change
L	400	6	6.9 kv, semirural	6.9 kv, semirural	6.9 kv, semirural	—	—	16,000(E)	—	190	—	Severe locally	Filter installed; reduced TIF and I·T about 4 to 1

* Measured except where noted by (E)—estimated.

** Voltage TIF at generator bus.

*** Range among 4 similar installations.

phase-wires (because of mutual inductance between them or between them and a multi-grounded neutral) may cause a fairly large proportion of this harmonic current to become ground return. This can be illustrated by the following (rather extreme) example:

1. Assume a 180-kva capacitor bank located two miles away on a 4-kv feeder from a 3,000-kva supply transformer bank with five per cent reactance. Assume 60-cycle phase-to-neutral impedance as follows:

Transformers	$j0.29$ ohm
Line:	
Phase 1	$j1.6$ ohms
Phase 2	$j1.65$ ohms
Phase 3	$j1.71$ ohms
Capacitors	$-j96.$ ohms

2. Assume that a seventh harmonic voltage exists in the circuit impressed with the power supply. The reactances at that frequency are:

Transformers	$j2.0$ ohms
Line:	
Phase 1	$j11.2$ ohms
Phase 2	$j11.6$ ohms
Phase 3	$j12.0$ ohms
Capacitors	$-j13.7$ ohms
Totals are:	
Phase 1 = $j13.2 - j13.7 =$	$-j0.5$ ohm
Phase 2 = $j13.6 - j13.7 =$	$-j0.1$ ohm
Phase 3 = $j14.0 - j13.7 =$	$j0.3$ ohm

3. If the harmonic voltages impressed on the three phases are equal, it can be seen that (neglecting resistances) the harmonic current in phase 2 will be about five times that in phase 1 and three times that in phase 3. Also, the current in phases 1 and 2 lead the impressed voltages; in phase 3 it lags the impressed voltage. The vector sum will be larger than the current in any of the phases; about 60 per cent of this vector sum will be ground return.

Examples From Field Experience

A few examples of situations encountered in the field which illustrate some of the foregoing principles are outlined:

1. One of the early large electrometallurgical rectifier installations was operated for a time with several 12-phase units and one 6-phase unit. The voltage TIF on the 154-kv supply at the rectifier was about 75. After traversing over 150 miles of transmission line, passing by a large generating station, and being impressed on a rural line, the voltage TIF was close to 500. The voltage TIF at numerous places within about 200 miles was higher than at the rectifier.

2. There have been cases where difficulties were encountered in the operation of rectifiers because of excessive fifth harmonic voltage either because of high impedance at that frequency looking out from the rectifier because of parallel resonance or because of stepup of fifth harmonic voltage arising in other sources because of series resonance.

3. In a number of cases, large changes have been noted at irregular times in the severity of inductive exposures (usually involving rural power circuits) without any apparent cause. In several of them, these changes were finally associated with opening or closing of circuit breakers on the transmission line network, in some cases literally hundreds of miles away. Evidently, changes in propagation conditions on the transmission system resulting from the operation of the breakers were responsible.

4. In one of the first metallurgical rectifier installations to employ a large bank of capacitors, an attempt was made to determine the effects on inductive co-ordination of operation with certain rectifier units shut down in the presence of suspected resonance between the capacitors and the power system at one of the frequencies normally suppressed by phase multiplication. The attempt was abandoned because of difficulties in rectifier operation and danger of burning out the capacitors because of large currents at the resonant frequency.

5. One of the sharpest resonance cases encountered was between a rural line and the transformer feeding it. Here a modest 1,880-cycle voltage was stepped up to about 20 per cent of the rms; the 1,880-cycle current was larger than the 60-cycle current.

6. Very large fifth harmonic currents have been observed in power factor correction capacitors on distribution systems because of resonance, and some cases of capacitor overheating have been observed, mainly in installations by power company customers and because of resonance with the supply transformers.

7. One of the highest voltage TIF's on record, about 2,500, was caused by about a four to one stepup caused by resonance between a small generator and transformer and a rural power line.

Appendix III. Examples of Types of Situations Studied

In Table XII a few of the installations which have been studied are summarized. The examples listed there were chosen to represent a number of different types of situations.

Items *A* through *D* are typical of very large installations and are included to illustrate several factors, namely:

1. The large advantage of phase multiplication, for example, compare examples *A* and A^1, which are for the same installation before and after phase multiplication was applied.

2. The further reduction in influence obtained through the use of large banks of capacitors installed for power operating reasons (see example *B*).

3. Example *D* illustrates the type of situation which occasionally arises where some difficulty may be experienced even with 36 phases, particularly when one unit is out of service. In this situation, during the existence of the unfavorable power layout, the removal of units for maintenance was confined as far as practicable to periods of low telephone traffic.

Items *E*, *F*, *G*, and *H* are street railway rectifier installations chosen to illustrate a range of conditions. Item *E* illustrates a rather extreme condition in that while most factors involved were favorable, there was a condition of resonance between an extensive cable network and a large generating station which accentuated the seventeenth and nineteenth harmonics. Changing to 12-phase operation greatly reduced these harmonics and practically eliminated the problem. Items *F* and *G* are two similar street railway rectifiers installed in the same city and supplied over about the same length of the same type of feeder. The only difference was that in case *F* the feeder supplying the rectifier also supplied an extensive distribution system; in case *G* the feeder ended at the rectifier. The reason for the unusually large values of I·T in these cases is imperfect suppression of the seventeenth and nineteenth harmonics in the 12-phase arrangement. This condition was rather common in earlier rectifiers; it is seldom observed in more recent installations.

Item *H* is typical of many thousands of kilowatts of street railway rectifiers which have produced no problems on the a-c side but have occasionally produced problems on the d-c side.

Items *I* and *J* are radio station rectifiers and are included primarily to illustrate how the inductive effects are likely to be increased when the rectifiers are installed away from densely developed areas. A larger proportion of radio station rectifiers have caused co-ordination problems than any other class of installation because of this fact.

Items *K* and *L* illustrate again the difference in effects of relatively small rectifiers depending on location and power system conditions. Installation *K* is one of several in a very heavy industrial area and illustrates the type of situation where harmonic control would be desirable if cheaper methods were available; the influence and noise conditions are on the ragged edge, with little margin for future changes. Installation *L* is in a much less heavily developed area.

References

AIEE Papers

1. Effects of Rectifiers on System Wave Shape, P. W. Blye, H. E. Kent. AIEE Transactions, volume 53, 1934, January section, pages 54–63.

2. Current and Voltage Wave Shape of Mercury Arc Rectifiers, H. D. Brown, J. J. Smith. AIEE Transactions, volume 52, 1933, pages 973–84.

3. Harmonics and Load Balance of Multiphase Rectifiers: Considerations in the Selection of the Number of Rectifier Phases, R. D. Evans. AIEE Transactions, volume 62, 1943, April section, pages 189–7.

4. A Short-Cut Method of Estimating Telephone-Influence Factor of Power Systems With Rectifier Load, C. W. Frick. AIEE Transactions, volume 63, 1944, March section, pages 91–6.

5. Wave Shape of 30- and 60-Phase Rectifier Groups, O. K. Marti, T. A. Taylor. AIEE Transactions, volume 59, 1940, April section, pages 218–24.

6. Electric Equipment for Large Electrochemical Installations, T. R. Rhea, H. H. Zielinski. AIEE Transactions, volume 61, 1942, October section, pages 733–41.

7. Ignitron Rectifiers in Industry, J. H. Cox, G. F. Jones. AIEE Transactions, volume 61, 1942, October section, pages 713–18.

8. Harmonics in the A-C Circuits of Grid-Controlled Rectifiers and Inverters, R. D. Evans, H. N. Muller, Jr. AIEE Transactions, volume 58, 1939, pages 861–70.

9. Analysis of Rectifier Circuits, E. F. Christensen, C. H. Willis, C. C. Herskind. AIEE Transactions, volume 63, 1944, pages 1048–58.

10. Inductive Co-ordination of Common-Neutral Power-Distribution Systems and Telephone Circuits, J. O'R. Coleman, R. F. Davis. AIEE Transactions, volume 56, 1937, January section, pages 17–26, 189.

11. Noise Co-ordination of Rural Power and Telephone Systems, H. W. Wahlquist, T. A. Taylor. AIEE Transactions, volume 57, 1938, November section, pages 613–20.

12. Inductive Co-ordination of REA Distribution Systems and Telephone Systems, K. J. Pinckaett, W. T. Smith, T. A. Taylor. AIEE Transactions, volume 60, 1941, pages 586–95.

13. Measurement of Telephone Noise and Power Wave Shape, J. M. Barstow, P. W. Blye, H. E. Kent. AIEE Transactions, volume 54, 1935, December section, pages 1307–15.

14. First Report of Power System Stability, AIEE Subcommittee on Interconnection and Stability Factors. AIEE Transactions, volume 56, 1937, February section, pages 261–82.

15. The Electronic Converter for Exchange of Power, F. W. Cramer, L. W. Morton, A. O. Darling. AIEE Transactions, volume 63, 1944, pages 1059–69 and discussion, page 1413.

16. Operation of Nonsalient-Pole-Type Generators Supplying a Rectifier Load, M. D. Ross, J. W. Batchelor. AIEE Transactions, 1943, November section, pages 667–70.

Reports of Joint Subcommittee on Development and Research, Edison Electric Institute and Bell Telephone System

17. Wave-Shape Characteristics of Power Circuits Supplying Rectifiers, Engineering Report 23.

18. The Impedances of A-C Supply Systems at

Maintenance of Rectifiers on Electrochemical Installations

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Synopsis: Operating experiences and information gained over a period of years from the operation of a large group of mercury arc rectifiers have shown that, while rectifiers provide a very economical means of converting from a-c to d-c power, they are not entirely trouble free. The principal operating difficulty has been the seemingly inherent tendency for a rectifier to arc-back. This peculiarity has challenged both the designer and operator since it has been found that both contributte toward the solution. The present paper presents the features which have been found advisable for the operator to observe and control in order to keep the occurrences of arc-back at a minimum.

LARGE INSTALLATIONS of mercury arc rectifiers in the electrochemical industries of the United States made their first appearance in 1938 when they were installed to supply direct current necessary for the production of aluminum.

With the advent of the war and the demand for the light electrochemically produced metals, large amounts of direct current were required so that the development and installation of rectifiers was carried on very rapidly.

The details of the equipment[1] and the nature of the operating problems are well known.[2] Improvement in the operating characteristics of this relatively new apparatus is of interest to operating and design engineers. Possibilities for improvement, especially in the older or multi-anode design rectifiers, are disclosed in this paper covering the operating experience at one large installation. A broader view of remedies available possibly might be presented in discussions from other operating engineers, covering experience in irregular operation somewhat different from that of the installations on which this paper is based. Experience and observations reported cover equipment operated continuously at full load, which is peculiar to the electrochemical industry.

One of the oldest and most troublesome problems encountered in rectifier operation is the arc-back. Much research has been carried out on this problem and some improvement has resulted. In the 250-volt rectifiers, arc-backs are no longer a serious problem. With higher voltages the problem still exists to some extent, and there remains much to be learned about the cause and prevention of arc-backs.

It generally is agreed that the basic cause of an arc-back is the formation of a cathode spot on the anode. This spot destroys the valve action and constitutes a short circuit which must be cleared immediately. While there are several known causes for the formation of a cathode spot on an anode, a full explanation has not been found as yet, and it is believed that there are still many unknown causes.

In the various engineering publications, there is a wealth of highly technical data and discussion on arc-backs and their causes. Such data are available to all engineers and are not within the scope of this paper.

The equipment under consideration consists of rectifiers used in the production of aluminum. Two rectifiers are served by one transformer, which steps 13,200 volts down to 560 anode volts. The rectifiers covered are of three different types:

12 anode multianode type
12 tube ignitrons
12 tube excitrons

Figure 1 shows an inside view of one station of multianode rectifiers. Figure 2 shows one of these rectifiers with the anode plate assembly removed in order to repair a single anode.

The multianode rectifiers and the excitrons are of the grid controlled type. Voltage control is obtained by applying an adjustable negative potential to the grid, which correspondingly delays the firing of the anode. The ignitrons have a grid, but it is not used for voltage control. Ignitron voltage control is obtained by delaying the impulses to the ignitor. The main connections of a transformer and its rectifiers are shown in Figure 3.

Arc-backs are random in nature and are unpredictable. Some rectifiers have operated a year and a half without an arc-back, whereas others have had over a

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HARMONIC FREQUENCIES TO BALANCED COMPONENTS, Engineering Report 33.

19. THE IMPEDANCES OF A-C SUPPLY SYSTEMS AT HARMONIC FREQUENCIES TO RESIDUAL COMPONENTS, Engineering Report 34.

20. WAVE SHAPE OF MULTIPHASE RECTIFIERS, Engineering Report 49.

21. SELECTIVE DEVICES FOR REDUCING HARMONIC IN POWER SYSTEMS: PART I, D-C SYSTEMS, Engineering Report 21.

22. SELECTIVE DEVICES FOR REDUCING HARMONICS IN POWER SYSTEMS: PART II, A-C SYSTEMS, Engineering Report 34.

23. INDUCTIVE CO-ORDINATION OF RURAL POWER AND TELEPHONE SYSTEMS, Engineering Report 40.

24. THE USE OF POWER AND TELEPHONE TRANSPOSITIONS WITHIN EXPOSURE SECTIONS, Engineering Report 36.

25. EFFECTS OF BONDING AERIAL TELEPHONE CABLE SHEATH TO MULTIGROUNDED POWER NEUTRALS, Engineering Report 43.

26. SUSCEPTIVENESS OF SUBSCRIBER STATION SETS, Engineering Report 46.

27. RELATIVE INTERFERING EFFECTS OF DIFFERENT SINGLE FREQUENCY NOISES IN TELEPHONE CIRCUITS, Engineering Report 32.

28. THE TELEPHONE INFLUENCE FACTOR OF SUPPLY SYSTEM VOLTAGES AND CURRENTS, Engineering Report 33.

29. FREQUENCY WEIGHTING FOR MESSAGE CIRCUIT NOISE, Engineering Report 45.

Other Publications

30. REPORTS OF JOINT GENERAL COMMITTEE OF EDISON ELECTRIC INSTITUTE AND BELL TELEPHONE SYSTEM ON PHYSICAL RELATIONS BETWEEN ELECTRICAL SUPPLY AND SIGNAL SYSTEMS, Publication M5, Edison Electric Institute, New York, N. Y., July 1945.

31. RECTIFIER CIRCUIT POWER FACTORS, HARMONICS, AND WAVE SHAPES, R. D. EVANS. *Electrical World*, October 1943.

32. RECTIFIER WAVE SHAPE, Publication R1, Edison Electric Institute, New York, N. Y., April 1937.

33. MODERN DEVELOPMENTS IN RAILWAY SIGNALING. *Journal of the Institution of Electrical Engineers*, England, volume 78, page 353; volume 79, page 331.

34. PRINCIPLES OF MERCURY ARC RECTIFIERS AND THEIR CIRCUITS (book), D. C. Prince, P. B. Vogdes, McGraw-Hill Book Company, New York, N. Y., 1927.

35. MERCURY ARC POWER RECTIFIERS (book), Othmar K. Marti, Harold Winograd, McGraw-Hill Book Company, Inc., New York, N. Y., 1930.

36. MERCURY ARC CURRENT CONVERTERS (book). Rissik, Pitman, London, 1935.

37. ELECTRICAL TRANSMISSION AND DISTRIBUTION REFERENCE BOOK (book), Westinghouse Electric Corporation.

38. MERCURY ARC HEATING FREQUENCY CONVERTER, S. R. Durand, *Electronic Industries*, June 1945.

39. MERCURY ARC FREQUENCY CHANGER LIMITS ROLLING MILL DEMAND, R. W. Holman. *Electrical World*, April 13, 1946, pages 119-16.

hundred in that length of time. There are not sufficient data available to say what constitutes too many arc-backs, or how many such mechanical shocks a transformer will stand. The shock the transformer receives is proportional to the value of the arc-back current, and the use of high speed anode circuit breakers reduces this current and, consequently, the transformer shock. As to frequency, the authors have used a sort of par or standard permissible rate of one arc-back per month per rectifier. This figure was based to some extent upon the rate existing at the time it was established, but subsequent experience has indicated that this figure can be reduced materially for single-anode per tank rectifiers.

A group of multianode rectifiers showed an over-all average of 1.8 arc-backs per month per rectifier during the first six years operation. The individual performance over this same period ranged from 0.6 to 3.0 arc-backs per month average.

From an operating standpoint, arc-backs may be divided empirically into two classes, and for the want of better terms may be called normal and abnormal arc-backs. Normal arc-backs are those which occur during the normal steady state operation and for which no cause is evident. Abnormal arc-backs are those which occur during or after some interruption to normal operation, such as removal from service or abnormal temperature or vacuum.

Some rectifiers, especially the multianode type, may have a good normal arc-back rate and a bad abnormal rate. Thus a rectifier may become sensitive or reach a condition wherein it operates better than par on steady service, but if taken out of service for a few hours it may arc-back a dozen times within five or six hours after having been restored to service. Conversely, some may have a poor normal rate but not be sensitive to such removal from service.

The cause for this behavior is not understood fully, but possible causes are the presence of condensed mercury in the vicinity of the anodes or the introduction of contamination from the anode shaft seals. The latter could result from the slight expansion and contraction of the shafts from temperature changes.

Operating Conditions

The majority of abnormal arc-backs are caused by contamination or leaks. Other causes are abnormal temperature or vacuum and excessively delayed firing for voltage control. Also, there are indications that some arc-backs are caused by droplets of liquid mercury or mercury dew on the anode or other surfaces at anode potential. Such arc-backs may occur after the rectifier has been out of service a short time and has cooled down somewhat. For example, there have been instances where the rectifier arced back as soon as the anodes were energized, even though there was no excitation or any d-c back feed. Sometimes four or five arc-backs would clear the trouble, but in other cases the bad anode would have to be disconnected for a few hours, after which it would operate normally.

Figure 1. Interior view of one station of multianode rectifiers

High temperature of cooling water tends to cause arc-backs but does not seem to be critical, because a good rectifier will permit a considerable increase of temperature without apparent bad effects. As an experiment a rectifier, whose normal jacket water temperature was 52 degrees centigrade, was operated about 24 hours at a temperature of 95 degrees centigrade without an arc-back. This rectifier, however, was one with a good record. A so-called sensitive rectifier very likely would arc-back under such treatment.

Shortly after a number of ignitrons were placed in service, a very prolific cause of arc-backs was found to be the splashing of mercury against the grid and anode. A small pocket in the bottom of the individual tank vacuum valves eventually filled with condensed mercury and overflowed down the pipe and against the baffle, and some of course went through the holes and against the anode itself. These arc-backs frequently set off one or more additional arc-backs. The accepted explanation of this phenomenon is that the concussion precipitates the overflow of the pockets in other valves.

This trouble was corrected by installing internal baffles to prevent the mercury from reaching the anode.

Contamination

During the assembly of a rectifier, a certain amount of foreign material unavoidably is left in the tubes. Such material may consist of dust in the air, lint and dirt from workmen's clothing and wiping rags, residue from cleaning fluids, sand-blasting, and possibly other cleaning methods. New parts and the mercury itself may contain some impurities.

Some materials are much worse than others. Oil and grease, for example, are particularly bad, and their presence always will result in arc-backs. On the other hand, such materials as coarse sand, steel shavings, and broken porcelain insulation do not seem to cause much trouble. Even the lint from wiping rags and clothing does not cause as much trouble as would be expected.

In general, every effort should be made to keep the internal parts of rectifiers as clean as possible. The manufacturers and those industries that use a large number of rectifiers find it advisable to have a special air-conditioned room for opening and repairing rectifiers. Such a room should be controlled as to temperature and humidity.

Cleaning fluids, such as pure grade benzene (benzol), should be tested before using. An easy test is to evaporate about a pint and note the residue. If there is enough residue to be visible, it should not be used.

Where the various seals are made of materials such as rubber or asbestos, a certain amount of contamination may

come from these seals unless they are made suitably. During the war, for instance, some rubber gaskets were replaced by synthetic rubber. Under the influence of heat and vacuum, these gaskets liberated surprising amounts of compound into the tanks, and caused so many arc-backs that overhaul was required.

There has been no trouble which could be ascribed definitely to contaminated mercury. Such impurities as it may collect tend to rise to the surface where they are easily removed. A clean bright surface usually indicates satisfactory condition. It appears to be very difficult to make any laboratory tests which are any more reliable than visual inspection. Furthermore, the presence of certain kinds of foreign materials does not seem to cause any trouble.

As an experiment, several ignitrons were contaminated purposely with copper, tin, zinc, silver, and alumina (Al_2O_3), only one material, of course, being in each tank.

These materials have been in the rectifiers for periods ranging from seven months to a year and have a total of only two arc-backs for the five tanks. The only one examined to date is the one with the copper, which operated nearly a year without a single arc-back. Most of the copper was deposited conspicuously on the cooling coil and its support. The quartz ring in the mercury was definitely copper colored and a faint copper color was evident in spots on the grid. The scum on top of the mercury showed positive traces of copper, and there was some evidence of a slight amalgamation of the copper in the mercury, although this was not certain.

Mercury, which is removed from a rectifier cathode, always is given a standard cleaning treatment. This treatment consists of washing in nitric acid and distilled water, and then a double distillation is made. Mercury, which is suspected of containing oil, is given an extra washing with either grain alcohol or chemically pure benzol. The surface of clean mercury should be absolutely clear with no specks or film visible under a strong light.

Tests and Repairs

When the arc-back frequency shows a sudden increase or becomes what is considered excessive, the first step is to determine which anode or anodes are responsible. There are various devices and methods for indicating this action. One method, that has proved quite satisfactory, involves the use of a standard commercial surge-crest ammeter, which consists of a meter that measures the amount and direction of the magnetism in a special small magnetic link. One of these links is placed about six inches from each anode cable. The reverse current from the arc-back magnetizes the link correspondingly, so that the identity and magnitude of the arc-back can be determined by measuring the links after an arc-back with the surge-crest ammeter.

Figure 2. Assembly of cooling coil and anode plate for multianode rectifier

When such tests show only one anode in trouble, this one anode is usually repaired alone. If it is a multianode type rectifier it is opened and the one anode repaired. A special effort always is made to complete the work and close the rectifier up the same day, since with a short exposure time the degassing period can be shortened to a few hours.

Many of these single anode arc-backs are caused by leaks in the vicinity of the anode. This fact is especially true on seals consisting of organic material. Other causes are found in the anode assembly, such as broken grid insulation. Where there are two anodes in parallel, a broken grid wire on one will overload one anode, thereby tending to cause arc-backs. On the ignitrons a broken or wetted ignitor will have the same effect.

When the arc-back pattern is scattered over all or several anodes, and the rectifier is not a newly repaired one, an air or water leak is suspected first. Such a leak may be in the vacuum manifold, pumps, or some location an appreciable distance from an anode, so that its effect may be distributed over the whole rectifier. The easiest and first test for leaks is a hot pressure rise test, in which the low vacuum pump is stopped and the pressure rise noted for about an hour with the rectifier on normal load. A good rectifier will operate for hours with only a few microns increase in pressure. In fact, they have been known to operate a couple of weeks with the main valve closed and both pumps down. If there is a serious leak, the pressure should rise sharply in an hour or less. This pump stop test may be supplemented or confirmed by a cold pressure rise test. In this test the rectifier is cooled first to room temperature, and then the main vacuum valve is closed for several hours and the pressure rise noted. The temperature of the rectifier should be constant of course during the check period. The permissible rise for such a test varies with the types and sizes of rectifier tanks, but a rough figure is from three to six microns in six hours. Some tubes will show as little as one micron rise in this period, while others as much as 10 or 12 and still be acceptable. Some air leaks sufficient to cause arc-backs may be within the pump capacity and, consequently, not show up on the vacuum meter. These leaks will be indicated, however, by the foregoing tests, and in some cases can be measured with a low reading gas meter.

If these tests indicate that there are no

air leaks, then contamination, water leaks, or internal trouble is suspected, and the only course is to open the rectifier.

Air and water leaks leave a certain amount of discoloration at their source. Contamination usually leaves some discoloration or spots, and in some cases a definite deposit on surfaces near the source.

The inside appearance varies considerably with different rectifiers. On some the inside of the tank and the cooling coils have a dark smoked appearance, whereas others show various temper colors of blue and straw. Air leaks usually leave a light brown rust deposit on the metal surfaces. On others a great portion of the surface is white because of the amalgamation of mercury vapor.

The inside of the tank and the cooling coils are sandblasted. Finished steel surfaces are polished with emery cloth. All cleaned surfaces then are wiped with a clean lintfree rag and a cleaning fluid such as pure benzene. Insulating parts also are sandblasted and cleaned the same way.

Great care and cleanliness must be used in the assembly. A touch by the bare skin on a finished surface will produce a small rust spot which is a possible source of contamination. Clean cotton gloves and clothing must be worn while making the assembly.

In most cases the same cathode mercury possibly could be reused by skimming off the surface, but it is advisable to use only mercury which has been renovated thoroughly, as previously described.

In old rectifiers the insulating parts which are exposed always show a certain amount of metallization. This metallization is a gradual process in which metal from the steel parts is deposited on the various insulating parts. The actual causes and details of the transfer of metal does not seem to be understood thoroughly, but one theory is that the arc stream for some reason may be diverted from its normal path and travel through some steel part, such as the cooling coil or tank wall, thereby vaporizing some of the metal. Pitted spots have been found in rectifiers which indicates that this phenomenon occurs.

Under normal operation the metallization is quite slow and may require years to become critical. At the other extreme, there are cases where it became so bad within a few weeks that the rectifier had to be reopened and cleaned. In such cases there is always a reason for this condition which may or may not be discovered. Improper degassing operation, in which the pressure is allowed to run too high, excessive tank temperature, leaks, and contamination will hasten the process of metallization.

When this metallization has progressed far enough, the insulating value of the insulating parts is impaired to a point where improper operation results. Thus the grid and anode insulation may become so low that the grid will receive its potential from the anode instead of its regular source, and, consequently, lose its voltage control ability. In the final stages of metallization, the arc-back rate increases and the rectifier must be opened and cleaned.

Degassing

When a rectifier has been exposed to air, it must be degassed in order to remove the gas which was absorbed during the exposure.

The degassing time depends to a great extent upon the length of the exposure time. Thus a rectifier, which has been opened and closed the same day with an exposure of only a few hours, can be degassed in a few hours. On these short exposures, it is possible to degas in service on line voltage at low loads, and, while this practice sometimes is followed, it has been found better to give it at least a short period on short circuit degassing.

A "green" rectifier, that is, one which has been opened for several days, requires from 60 to 120 hours of degassing.

The common practice in degassing is to short circuit the rectifier by connecting the cathode to the transformer neutral (the negative line) and apply 40 to 80 volts to the anodes. On 13-kv transformers, for example, 1,700 to 2,300 volts on the primary makes a satisfactory degassing voltage for 600-volt class rectifiers. On grid control type rectifiers, there should be some resistance in series with each anode in order to insure proper load division. This resistance is of the order of one-half to one ohm at the start and is reduced as degassing progresses. At about three-quarters of the rated full load current, the resistance may be removed if desired and the degassing finished without resistors. The short circuit current is controlled by the regular voltage control method of either grid bias or ignitor phase shift, depending upon the type of rectifier.

Ignitrons may be degassed satisfactorily without anode resistors even when "green." Some users, however, insert a low resistance of about one-fourth ohm in each anode until the current has reached

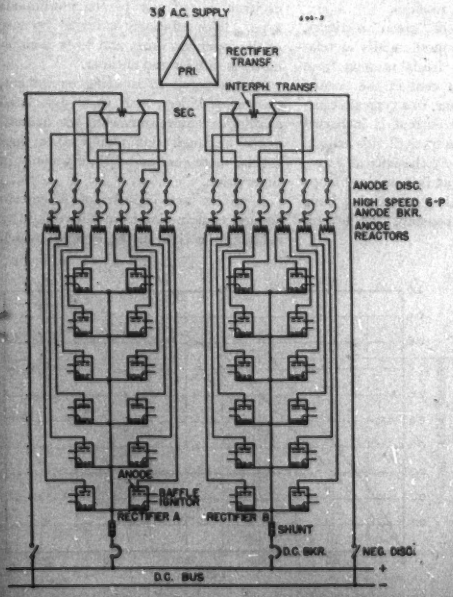

Figure 3. Unit connection diagram for ignitron rectifier

Figure 4. Anode and grid assembly of an ignitron

one-fourth to one-third rated value. This resistor balances the anode currents and results in a more uniform cathode current.

The degassing current is started at about two per cent of normal for multianode tubes and about ten per cent of normal for ignitron tubes, and increased as fast as the vacuum will permit. Before starting, the tube is pumped down to practically zero pressure on both the McLeod and electric gauges. During the degassing period, the vacuum on the multianode rectifiers is held within two microns on the McLeod gauge, and from four to ten microns on the electric gauge. The higher indication of the electric gauge during degassing is caused by the presence of condensable gases, which are not recognized by the McLeod gauge. After the rectifier has been degassed thoroughly, both gauges will settle down to approximately the same reading.

Ignitrons may be degassed with a somewhat higher pressure than the multianode type. McLeod readings of four or five microns and electric gauge readings of 12 to 15 microns are permissible on the ignitrons.

While the liberation of gas is fairly uniform during most of the degassing period, the gas occasionally will come out in sudden bursts or bubbles as though a pocket were released. When this action occurs, the degassing current must be reduced or removed to enable the vacuum pumps to restore proper vacuum. There are evidences that such pockets develop after the rectifier has been degassed and put back in service. For example, there have been several instances in which an arc-back on a recently overhauled rectifier was accompanied by sufficient increase of pressure to show on the vacuum gauge. This condition existed for only a few minutes.

After the regular degassing period, a rectifier occasionally continues to liberate a measurable amount of gas for several days, or even weeks after it is back in normal service. For electrochemical service it has been found advisable to finish a degassing operation by applying an overload current of 25 to 50 per cent for a few hours, in order to remove as much gas as possible. During the degassing period, a large rectifier will liberate from one-half to nearly one cubic foot of noncondensable gas. Figure 5 shows the time-gas volume curves obtained at Alcoa from the degassing of two "green" rectifiers selected at random.

In the degassing of "green" rectifiers, the gas is liberated most rapidly at relatively low current loads ranging from about 15 to 40 per cent of the normal operating load. Thus, in a typical degassing operation, the current is increased more or less uniformly until this critical value is reached. At the critical value, the gas is released as fast as the pumps can handle it, and the current may have to be maintained constant for several hours.

Having once passed this "hump," it progresses more rapidly as the load is increased. When a rectifier has been given a complete overhaul and placed back in service, it occasionally will arc-back several times during the first week or so, after which it settles down gradually to good performance.

It is believed that this behavior is caused by contamination left in the tube after overhaul. In order to hasten decontamination, a process called "aeration" has been tried several times at Alcoa. This process consists of cooling the rectifier and admitting clean dry air for some two or three hours. This air is admitted through a tube containing a filter and a drying agent, such as activated alumina. The air then is pumped out and the rectifier degassed on full voltage and a slowly increased load. The theory of this "aeration" is that a certain amount of the contaminants are oxidized and mixed with the air, and these products are pumped out sooner than they would be in normal operation. Engineers are not in full agreement on this theory, but favorable results have been obtained and the method should be given thorough trial.

Conclusions

It generally is agreed that the single anode type, such as the ignitron and the excitron, is superior to the multianode type. Their efficiency is higher because of the lower arc drop, and their maintenance is simpler and cheaper.

As compared to rotating equipment, modern rectifiers with their associated auxiliaries require somewhat less maintenance although this maintenance does require more care and skill, especially in supervision.

Rectifiers are capable of a certain amount of reduction from full voltage by delaying the time in the cycle at which

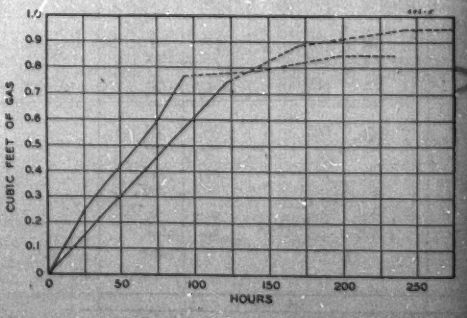

Figure 5. Time-gas volume curves obtained from the degassing of two "green" rectifiers selected at random

——— Degassing
------ On line

the anode begins passing current. Such control is obtained at the expense of an increase in arc-back frequency, a lower power factor, and a slight decrease in efficiency. The greater the reduction, the more pronounced are these undesirable effects, so that reduction in excess of some 15 or 20 per cent is of doubtful value. For this reason it is preferable to operate with the minimum firing delay compatible with operating conditions. This voltage control feature stands in need of further improvement.

Inasmuch as a cold rectifier is more likely to arc-back, means must be provided to keep them warm. For continuous service this is no great problem, but for intermittent service suitable heaters usually are provided.

One of the most vulnerable points of a rectifier is the seals. These seals have been improved much in recent years, but there is still room for further improvement. This fact is especially true where they are made of organic materials, such as rubber and fiber.

There is not yet sufficient operating experience to say definitely how long a pumped type rectifier will operate before requiring a major overhaul, but the authors' experience would indicate a period of not less than six or seven years with continuous operation and uniform load. Aside from damage or failure of parts, the long time factor that should dictate a major overhaul is the metallization of parts or possibly an excessive amount of carbon in the mercury pool. Some minor repairs, such as ignitor renewal or seal repair, should be expected during the period.

From the user's standpoint, the outstanding problem is the cause and elimination of arc-backs. They are so unpredictable and so many occur without any known cause that they are a constant challenge to engineers and operators.

Among the known causes, contamination should have a great deal more study. There is much uncertainty as to the nature and amount of contamination necessary to cause serious trouble.

Since rectifiers are still on the threshold of their development, it is expected that future developments and research will simplify operation and reduce present maintenance problems.

References

1. Alcoa Rectifier Installation, J. Elmer Housley, H. Winograd. AIEE Transactions, volume 60, 1941, pages 1266–74.

2. Aspects of the Operation of Mercury Arc Rectifier Stations, J. Elmer Housley, J. H. Studley. Transactions, Electrochemical Society, volume 86, 1944, pages 169–85.

Fault Location and Relay Performance Analysis by Automatic Oscillographs

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Synopsis: The purpose of this paper is to describe a method developed for determining the location of ground faults on an extensive 140-kv grounded neutral transmission system. This method applies particularly to ground faults in a network of two or more parallel lines and is based on a comparison of the magnitude of ground currents in the faulted circuit and in the unfaulted circuits. Since the relative distribution of ground fault current in a network depends only on the zero sequence impedance of the system, an analysis of ground faults by comparison is independent of generation, fault resistance, or whether one or two phases are involved to ground. The paper also describes the use of ground fault current curves in determining the critical conditions for relay selectivity and summarizes the results of five years of satisfactory experience with automatic oscillographs used in the analysis of faults and relay operations on the system.

THE SYSTEM referred to in this discussion includes nearly 1,000 miles of line widely distributed over the State of Michigan, as shown geographically in Figure 1. The first automatic oscillograph was installed in 1931, and two more were added in 1935. These were used at various points on the system to study system behavior. In 1941 an additional one was acquired, and the four instruments were located permanently to coordinate fault records on the 140-kv grounded neutral system. In the period from 1941 to 1945 inclusive, oscillographic records were obtained for approximately 250 line faults. These records showed 96 per cent of the line faults involved either one or two conductors to ground. From this, it is obvious that fault studies on this system are concerned primarily with ground currents, and the location of the oscillographs and the element connections have been selected to give maximum information on ground faults.

Location and Initiation of Oscillographs

The instruments are located at the four principal neutral grounding points on the system: Croton Station on the Muskegon River, Morrow Station east of Kalamazoo, Blackstone Station at Jackson, and Weadock Station, Bay City. Initiation of the oscillographs is by instantaneous undervoltage relays connected to 140-kv potential devices and by instantaneous overcurrent relays in the 140-kv neutrals of the grounded transformer banks. The initiating relays are set to insure operation of at least two oscillographs for all faults within the network. It is a decided advantage in ground fault analysis to have films from two instruments for comparing current values or for determining the total fault current. In the event that one instrument fails to operate, a fairly satisfactory analysis may be made from one film.

Connection of Elements

The oscillographs in service are the 6-element type using sensitized paper. Except as noted, three elements of each instrument are used to record line-to-neutral voltage, and three are connected in the current transformer neutrals of the lines to record ground current. At the Morrow Station, four elements are required for residual current in the lines, leaving only two elements available for potential indication. These are connected to record line-to-line voltage.

Calibration

Records obtained on automatic oscillographs are no more accurate than the calibration data. In determining the values to be used for current calibration, it is first necessary to calculate the maximum value of fault current that may be obtained in the various elements, and to decide on the maximum amplitude that may be permitted on each element with maximum fault current. On elements centrally located on the paper, the total amplitude must be less than the width of the paper. On elements located near the top or bottom of the paper, it is not necessary to restrict the amplitude so that both the top and the bottom of the wave is confined to the paper under fault conditions. The zero line of the element can be drawn in readily and the total amplitude determined from the half wave which remains on the paper. For calibration tests a total amplitude of 12 millimeters on potential elements and 15 to 20 millimeters on current elements has proved satisfactory. A total amplitude of 12 millimeters is taken to mean six millimeters above and below the zero line.

Adequate account should be taken of the breakdown of current transformer ratios when measuring ground current, and in converting calibration test data into terms of primary ground current, the effective current transformer ratio must be used.

Valuable information has been obtained on relay and circuit breaker operating time by using a bias or offset on the current elements. This is obtained by connecting a shunt in the d-c trip circuit of the breaker to its respective element, causing the center line to shift when the trip circuit is energized. This is shown in Figure 7.

Factors Used in Ground Fault Analysis

1. Magnitude and relative values of ground currents from each end of the faulted circuit with both ends closed.
2. Magnitude of ground current in the faulted circuit after one end opens.
3. Relative values and direction of ground currents in unfaulted circuits in parallel with the faulted circuit.

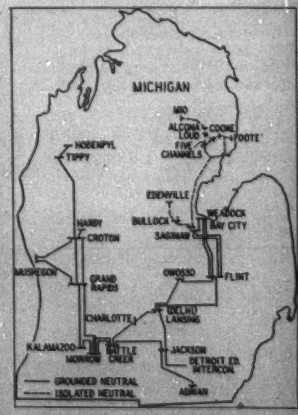

Figure 1. Consumers Power Company 140-kv system (1945)

Paper 46-109, recommended by the AIEE committee on protective devices for presentation at the AIEE summer convention, Detroit, Mich., June 24-28, 1946. Manuscript submitted March 18, 1946; made available for printing May 1, 1946.

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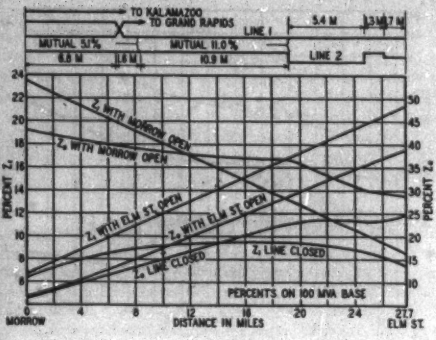


Figure 2. Curves of total fault impedance for line 1 and characteristics of line 1 and line 2 from Morrow Station to Elm Street Station, Battle Creek

(*a*). Both ends of the faulted circuits closed.

(*b*). After one end of the faulted circuit opens.

4. Magnitude and relative values of currents in contributing circuits from ground sources.

5. Recorded potential.

6. Changes in magnitude of ground fault current with changes in the nature of the fault, that is, one line to ground changing to two lines to ground.

7. Relay operation.

(*a*). Operating time of time delay relays.

(*b*). Pickup and operating range of instantaneous relays.

Calculations for Ground Fault Curves

Making up ground fault curves requires a considerable amount of work, but once completed, they provide a fast and accurate means of locating faults. A complete set of curves to utilize these factors consists of impedance curves, maximum ground fault current curves, and ratio curves.

The first step in making up data for curves is to have positive and zero sequence diagrams of the system and to calculate the positive, negative, and zero impedance for the total system at each station and at a sufficient number of points on the lines between stations to insure the drawing of accurate curves. On the average length of line, three or four points will be sufficient. Similar calculations are made for the lines open at either end. Ordinarily the positive and negative sequence impedances can be assumed to be equal. Calculations can be simplified by using linear values of impedance rather than the complex $R + jX$ form and are usually sufficiently accurate. If system generating conditions require the switching of grounded transformers which change the relative distribution of ground current, it may be necessary to make up more than one set of curves. As will be explained later, a second set of curves is not necessary for changes in generation only.

When calculating the total zero sequence impedance at each point, it is necessary to determine the distribution of ground current, not only in the faulted circuit but also in the parallel circuits and other contributing circuits. This is especially important for parallel circuits having mutual relation with the faulted circuit. For systems not involving too many mutuals, these values may be calculated by setting up mutual equivalents[1] or by simultaneous equations. It is important that fault points be taken at the ends of mutual sections, as the ground current curves change their slope at these points. On complicated systems with multicircuit mutuals, it is advisable to use an a-c calculating board.

Values of the total positive sequence impedance are more easily calculated or can be obtained on a d-c board.

Application of Curves

The two 140-kv circuits between Morrow Station and Elm Street Station, Battle Creek, designated as line 1 and line 2, have characteristics as shown at the top of Figure 2. A complete set of curves for line 1 is reproduced for illustration.

Impedance Curves

Curves shown on Figure 2 are for maximum positive and zero sequence impedances with the line closed and with the line open at either end. These data are convenient for checking a fault location when the nature of the fault changes. For example, assume a single-line-to-ground fault changes to a two-line-to-ground fault. If positive and negative

Figure 3. Maximum current curves for single-line-to-ground faults on line 1, closed at Morrow and Elm Street

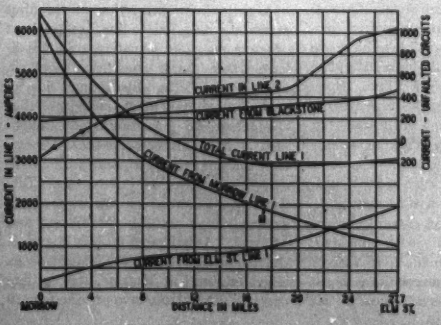
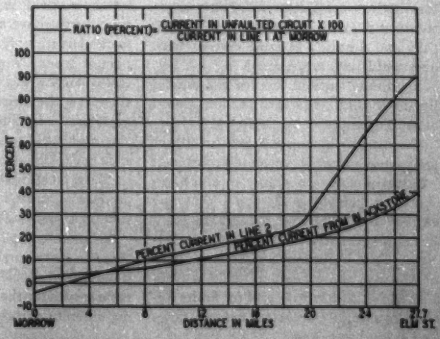


Figure 4. Ground current ratio curves for faults on line 1, closed at Morrow and Elm Street


RATIO (PERCENT) = CURRENT IN UNFAULTED CIRCUIT X 100 / CURRENT IN LINE 1 AT MORROW
PERCENT
PERCENT CURRENT IN LINE 2
PERCENT CURRENT FROM BLACKSTONE
DISTANCE IN MILES
MORROW
ELM ST.

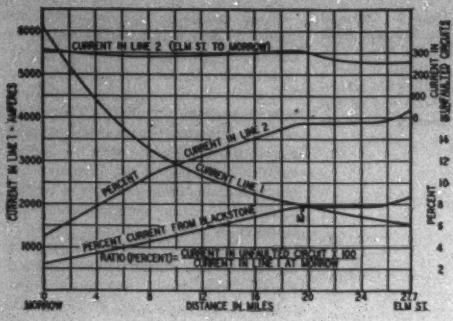

CURRENT IN LINE 2 (ELM ST. TO MORROW)
CURRENT IN LINE 2
CURRENT LINE 1
PERCENT
PERCENT CURRENT FROM BLACKSTONE
RATIO (PERCENT)= CURRENT IN UNFAULTED CIRCUIT X 100 / CURRENT IN LINE 1 AT MORROW
CURRENT IN LINE 1 - AMPERES
CURRENT IN UNFAULTED CIRCUIT
PERCENT
MORROW
DISTANCE IN MILES
ELM ST.

Figure 5. Maximum ground current curves and ratio curves for faults on line 1, open on Elm Street end

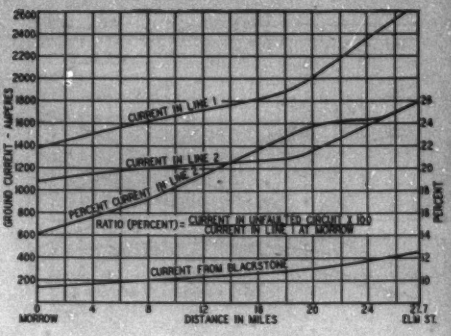

CURRENT IN LINE 1
CURRENT IN LINE 2
PERCENT CURRENT IN LINE 2
RATIO (PERCENT)= CURRENT IN UNFAULTED CIRCUIT X 100 / CURRENT IN LINE 1 AT MORROW
CURRENT FROM BLACKSTONE
GROUND CURRENT - AMPERES
PERCENT
MORROW
DISTANCE IN MILES
ELM ST.

Figure 6. Maximum ground current curves and ratio curves for faults on line 1, open on the Morrow end

phase impedances are considered equal,

Single-line-to-ground current

$$= \frac{3 \times 10^5}{(2Z_1 + Z_0)\sqrt{3}\ \text{kv}} \quad (1)$$

Two-line-to-ground current

$$= \frac{3 \times 10^5}{(Z_1 + 2Z_0)\sqrt{3}\ \text{kv}} \quad (2)$$

A value of Z_1 and Z_0 for the same location can be taken from the impedance curves which when applied in the above formulas will be equal to or proportional to the current values shown on the oscillograph film. This is usually a good indication of fault location, especially on a line section where there is a large variation in the ratio of Z_1/Z_0.

Current Curves

Current curves may be used directly in determining fault location if the fault currents are near maximum values. The curves are also very useful in determining the critical conditions for relay selectivity and for co-ordinating the magnitude and duration of fault current with observed line damage.

Maximum current curves for single-line-to-ground faults with the line closed at both ends are shown in Figure 3.

Curves for line 1 open at Elm Street and open at Morrow are shown combined with ratio curves in Figures 5 and 6, respectively. Note in Figure 3 that the current in line 2 passes through the zero line at about two miles from Morrow Station. That is, for faults within two miles of Morrow, the current in line 2 is from Elm Street to Morrow, and for faults beyond two miles, the current in line 2 flows from Morrow to Elm Street. Whether or not the current in a parallel circuit reverses after a circuit breaker opens on one end of the faulted line is often a definite indication of the fault location.

The difference in the slopes of the current curves in the 10.9-mile section and in the 5.4-mile section clearly indicates that the effect of mutual impedance cannot be neglected.

Ratio Curves

The distribution of ground fault current depends only on the zero sequence impedance of the system. The relative distribution in the faulted circuit and in parallel or contributing circuits is the same for one line-to-ground or for two line-to-ground faults. Fault resistance or changes in generation affect the magnitude of ground fault current but do not change the relative distribution. This fact can be utilized in making up a set of ratio curves independent of fault resistance and generation. Using the current in one circuit as a reference, the current in the other circuits can be plotted in per cent of the reference current.

It is apparent that fault locations can be determined more accurately if the ratio curves have a steep slope. On networks having only two currents to compare, it is not always possible to have one ratio curve that will have adequate slope over the entire length of line. However, nearly all line faults are cleared by the sequential opening of breakers at each end. This supplies data for making up three ratio curves, one of which can be used for accurate indication of fault location on a specific section of the line.

On more complicated networks where three or more currents can be compared, it may be advisable to make up two sets of ratio curves for the same condition by using different currents as reference. That is, by proper selection of reference currents, one curve may have a steep slope for a section of the line where the other curve is relatively flat.

Ratio curves apply specifically to faults with reduced values of current, but they can be applied equally well to faults with maximum current values. In some cases the ratio of currents may give a more definite indication than the individual currents.

The ratio curves of Figure 4 are obtained by plotting maximum current values, taken from Figure 3, in per cent of the current in line 1 at Morrow. Ratio curves with the line open at Elm Street and at Morrow are included in Figures 5 and 6.

Application of Oscillograph Data for Fault Location

The oscillograph films, Figure 7 and Figure 8, were obtained from Morrow Station and Blackstone Station respectively for a fault on line 1.

A preliminary inspection of the films shows the two line-to-line potentials at Morrow are approximately equal, indicating that the Z phase was involved. Reference to the Blackstone line-to-neutral potentials shows definitely that the fault was Z-phase-to-ground throughout. Further inspection of the film shows that the line opened at Elm Street in 19 cycles and at Morrow in 48 cycles. Targets were reported on the time delay ground relays at both Elm Street and Morrow. As indicated at M in Figure 5, the maximum reach of the instantaneous relays on line 1 at Morrow after the line opens at Elm Street is approximately 19

miles. Failure of this relay to operate indicates that the fault was more than 19 miles from Morrow or within nine miles of Elm Street. The bias was applied when the trip circuit at Morrow was energized. This shows that the oil circuit breaker on line 1 had five cycles clearing time.

Use of Current Curves

A detailed analysis gives measured values of fault currents in primary amperes as shown in Figures 7 and 8. The current values of the fifth and sixth elements of both films are not required in this analysis.

No film was obtained from Weadock for this fault, but previous calculations determined that for a fault at Elm Street, 51 per cent of the ground current from the eastern part of the system is contributed over the line from Blackstone, and 49 per cent over the line from Lansing. From the measured and calculated values of current, the distribution in the lines was as shown in Figure 9A for the initial fault and in Figure 9B after Elm Street opened. This gives a complete picture of the fault and indicates that the calculated total of 2,965 amperes was very nearly maximum current for a fault near Elm Street.

Applying the values shown in Figure 9A to the maximum current curves of Figure 3, the 1,400 amperes in line 1 from Morrow gives a fault location of 4.5 miles from Elm Street; 860 amperes in line 2 gives a location of four miles from Elm Street; 360 amperes from Blackstone gives a location of 5.5 miles from Elm Street; and the calculated value of 1,565 amperes in line 1 from Elm Street gives a location of 4.5 miles. This close agreement on fault location is a further indication that the fault currents were very nearly maximum value.

After the line opened at Elm Street, the values shown in Figure 9B applied to the current curves of Figure 5 give a location of five miles from Elm Street for 1,750 amperes in line 1, and 5.5 miles from Elm Street for 270 amperes in line 2. Note that the direction of current in line 2 reversed after line 1 opened at Elm Street. The curve of total amperes on Figure 3 is too flat at this point for close application, but the calculated total indicates the fault as being between four and six miles from Elm Street. All of the above determinations give the fault location as between 4 miles and 5.5 miles from Elm Street. The actual location was five miles from Elm Street, and the damage reported was three broken bells and light burns on the conductor.

Figure 7. Oscillogram from Morrow Station for a fault on line 1, Morrow to Battle Creek

Element 1. *YZ* phase potential
Element 2. *ZX* phase potential
Element 3. Ground current in line 1 to Battle Creek
Element 4. Ground current in line 2 to Battle Creek
Element 5. Ground current in Kalamazoo line
Element 6. Ground current in Grand Rapids line

Use of Ratio Curves

To illustrate the application of the ratio curves, assume that fault resistance or decreased generation had reduced the fault current to 80 per cent of the above values. Relative values then would be as shown in Figures 10A and 10B. Applying the values in Figure 10A to the current curves of Figure 3, the 1,120 amperes in line 1 from Morrow indicates the fault to be at or near Elm Street, while 690 amperes in line 2 places the fault at six miles from Elm Street, and 290 amperes from Blackstone gives the location as 14 miles from Elm Street. Similarly, the values of Figure 10B applied to the current curves of Figure 5 all indicate the fault as being at or near Elm Street. This wide discrepancy in the indicated fault location is characteristic of current values that are less than maximum and is an indication that the current curves cannot be directly applied, and the ratio curves should be used.

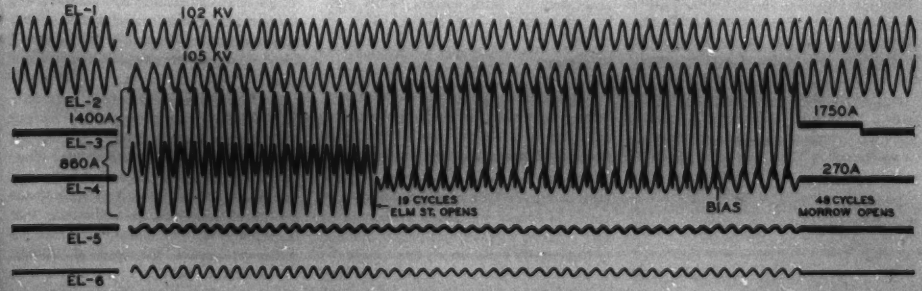
From the values of Figure 10A, the current in line 2 from Morrow is 61.5 per cent of the current in line 1 from Morrow, and the current from Blackstone is 26 per cent of the current in line 1. Applying these percentages to the ratio curves of Figure 4 gives fault locations of 4.5 miles and 4 miles from Elm Street as previously determined with actual fault currents. The currents in Figure 10B, after Elm Street opens, applied in the same way gives 15.5 per cent for the current in line 2 and 7.8 per cent for the current in the Blackstone line. These values fall on the flat part of the ratio curves of Figure 5 and serve only as a check.

From an inspection of the ratio curves of Figures 4, 5, and 6, it is evident that for faults within nine miles of Elm Street, the most accurate determinations can be made from the curves of Figure 4. For faults within 19 miles of Morrow, any one of the three sets of curves could be used with sufficient accuracy.

Other Applications of Oscillograph and Curve Data

Line Damage

During the past two years each fault analysis included calculations to correlate fault current and clearing time with the observed damage. In these calculations a factor has been used equal to (amperes/1,000)^3 × cycles. The currents used are taken from the oscillograph films supplemented by calculations and values from the current curves where necessary. For the actual fault discussed in this paper, the values used were 2,965 amperes for 19 cycles and 1,750 amperes for 29 cycles: $(KA)^3$ cycles = 255. While this study has not been carried on for a sufficient length of time to warrant any definite conclusions, it is indicated that the data may be



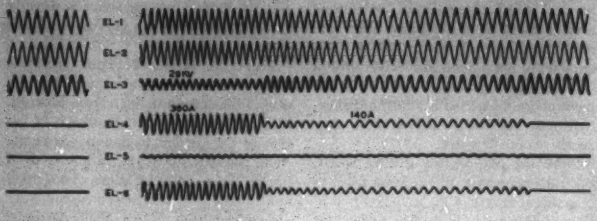


Figure 8. Oscillogram from Blackstone Station, Jackson, for a fault on line 1, Morrow to Battle Creek

Element 1. X-phase-to-neutral potential
Element 2. Y-phase-to-neutral potential
Element 3. Z-phase-to-neutral potential
Element 4. Ground current in line to Battle Creek
Element 5. Ground current in line to Lansing
Element 6. Ground current in interconnection

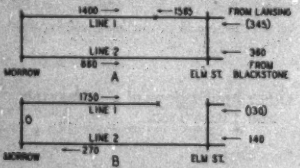


Figure 9. Distribution of maximum ground fault current

A. With line 1 closed at Morrow and Elm Street
B. After line 1 opened at Elm Street

of considerable value in determining whether or not a special patrol is necessary when no damage is found on the initial patrol.

Relay Performance

As a final step in the analysis, the operating time of each time delay ground relay is calculated for the value of ground current as measured on the films, and this calculated time is compared with the actual operating time as recorded. This furnishes a positive check on relay operation. In case of faulty films, this process can be reversed to calculate fault currents. Surprisingly accurate determinations have been made based entirely on relay operating time. Occasional faults

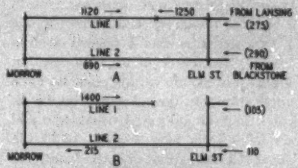


Figure 10. Distribution of ground fault current, 80 per cent of maximum

A. With line 1 closed at Morrow and Elm Street
B. After line 1 opened at Elm Street

near the end of the instantaneous relay zone supply data on the accuracy of pickup adjustment.

In the preparation of ground relay settings, the current curves are very useful in determining the critical points of selectivity. In many cases the critical point is at the end of the instantaneous relay zone where the time delay relay must be considered. This is especially true on parallel circuits with mutual couplings.

It can be seen in Figure 5 that the effect of the mutual is to maintain an almost constant value of current in line 2 for faults in the parallel section. And it is evident that faults on line 1 over 20 miles from Morrow may be critical for selectivity between the Elm Street relay on line 2 and the Morrow relay on line 1. Selectivity can be checked quickly and accurately by taking current values from the curves at any questionable point.

Summary

When making analyses of faults, it is of interest and value to prepare sheets for recording data on each fault. Tables I and II summarize the types and cause of

Table I. Types of Line Faults

Faults starting 1-line-to-ground	78%
Faults starting 2-line-to-ground	18%
Faults starting phase-to-phase	4%
Faults starting 1-line-to-ground and changing to 2-line-to-ground or to 3-phase	10%

Table II. Cause of Line Faults

Lightning	80.0%
Interference (birds, machinery, etc.)	9.0%
Wind	7.4%
Line material failure	1.2%
Unknown	2.4%

256 line faults analyzed over a period of five years. Exactly 50 per cent of these faults caused no visible damage and could not be located.

Conclusions

This method of determining ground fault location as developed by one of the authors has been in use for several years and has proved very satisfactory. For this discussion the particular line section and fault were selected to illustrate best some of the principles involved, and it should not be presumed that the same degree of accuracy can be obtained for all faults. With the present number of oscillographs on the system, the average degree of accuracy is in the order of ten per cent for faults in the network; that is, on a line 30 miles long it is expected that the faults can be located within three miles. With oscillographs at each station, it is probable that faults could be consistently located within one mile. The calculated locations of ground faults on radial lines are accurate only if tower footing and fault resistances are low.

One of the most important applications of the oscillograph is the information that is obtained when a fault is not cleared properly. In most cases these data definitely point to the cause of incorrect operation or failure to operate so that immediate steps can be taken to prevent a recurrence. By indicating the location of inconspicuous damage and potential sources of trouble, the oscillographs are becoming an increasingly important factor in transmission line maintenance. The diligent use of oscillograph data has resulted in greatly improved relay performance.

Reference

1. Equivalent Circuits, F. M. Staff. AIEE Transactions, volume 51, 1932, page 291.

Modern Diesel-Electric Drilling Rig Equipment

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Synopsis: A modern Diesel-electric powered drilling equipment for drilling oil wells consists of several internal combustion engines driving d-c generators, which supply adjustable voltage power to the several d-c motors driving the various motions. This paper gives a description of the functions performed by the draw works, mud pumps, rotary table, and coring reel, and a typical arrangement of apparatus or elementary power diagram showing the main d-c circuits with the arrangement of drill-hoist contactors and manual transfer switches. In addition, there are related the general scheme of operation, strictly from the driller's point of view, without the details of how these functions are accomplished; the operating principles of the electrohydraulic governor that make this scheme of operation possible; as well as the various control features provided by the amplidyne excitation of the main generators. The electrohydraulic governor, a war development, is applied for the first time to Diesel-electric drilling rig equipment. This governor gives to the engines a degree of protection never before attained, by preventing the engine from being overloaded. The governor also permits running the engines at the lowest speeds consistent with the desired rig motion and not at full rated speed at all times as in the past. The electrohydraulic governor provides for engine paralleling without the driller having to pay any attention to the engine throttles. The merits of a-c versus d-c auxiliary drives are pointed out, and separate engine-driven auxiliary a-c generators are recommended instead of the usual practice of driving auxiliary d-c generators from the main engines. This gives a saving in first cost of auxiliaries conservatively estimated at 25 per cent, as well as gains in simplicity, sturdiness, and less weight.

A MODERN Diesel-electric drilling rig equipment for drilling oil wells consists of several internal combustion engines driving d-c generators. These generators supply adjustable voltage power to the several d-c motors driving the draw works, mud pumps, rotary table, and coring reel.

Most oil well drilling is done by steam engines or Diesels that mechanically drive the various motions through a system of gears and clutches. However, oil wells are being drilled deeper in search of new sands, requiring more power. As in surface transportation and propulsion, the flexibility of transmitting this power electrically is becoming more and more evident.

It is estimated that approximately 35,000 wells will be drilled in 1946. The average depth will be about 4,500 feet. However, a great deal of the exploratory drilling between 10,000 and 15,000 feet now is being done with Diesel-electric equipment where its flexibility is of particular advantage.

It is the purpose of this paper to describe a typical modern Diesel-electric powered drilling equipment and not to discuss the relative economics of Diesel-electric versus mechanical and steam rigs.

Description of Functions

A modern deep well is drilled by means of a bit attached to a drill stem (drill stem is special hollow pipe) and rotated to bite through the sand, gravel, and rock formations of the earth's crust. The diameter of the hole may be 12 inches at the top and six or eight inches near the bottom of a 10,000- or 12,000-foot hole. For clarity, the functions of the various drives are given.

Draw Works

This equipment is the hoist for lifting the drill stem in and out of the hole, and a good view of it is shown in Figure 1. Bits have to be changed every day or two and sometimes every few hours. The draw works operates like a hoist with several mechanical gear changes. To change a bit, a section or two of drill stem is lifted out of the hole, unscrewed, stacked in the side of the derrick, and the traveling block and hook is lowered to pull up the string of drill stem another couple of sections, and so on. Usually, all engines are required for this operation while the mud pumps, rotary table, and coring reel remain idle.

Rotary Table

The rotary table rotates the drill stem with the bit on bottom and drills the hole. The driller regulates the weight of pipe permitted on the bit by means of a mechanical brake on the draw works. The chips and sand are removed by circulating mud.

Mud Pumps

The principal functions of the mud pumps are to circulate the mud which lubricates the drill stem and bit, pick up the chips and sand, and bring them to the surface, suspended in the mud, in the annular space between the drill stem and the outside steel casing, as illustrated in Figure 2. Getting the mud to the right consistency to do this job is a "black" art known only to the drillers. Keeping the mud flowing is important because a 10,000-foot column of mud has a burden of chips which will settle out at the bottom and may freeze the drill stem in the hole if left to stand for a few hours.

Coring Reel

This reel is a light-duty high-speed hoist used to remove sample cores from the hole and for logging purposes. It is used when other apparatus is not in use and is, mechanically, entirely independent.

Typical Arrangement of Apparatus

A typical arrangement of apparatus for 15,000 foot drilling is shown in Figure 3. In this example, three Diesel-engine-driven generators are shown. In some cases, four, five, or even six such sets are employed. However, the minimum rating of Diesel-engine set often is dictated by the rating of the mud pump so that one engine generator set can supply its full rating. The number of such sets is dictated by the rating of the draw works.

The auxiliary motor-driven apparatus, such as miscellaneous pumps and blowers, and the power-system used to supply it will be discussed later.

General Scheme of Operation

Perhaps it will give a better understanding of the equipment operation to describe the results obtained by modern electric equipment from the driller's point of view, before describing in detail the equipment used for accomplishing the results.

Each of the motors operates at constant field strength. Speed is controlled entirely by generator voltage (that is, by generator field and engine speed).

Assume that on Monday morning all equipment is at rest. The engines are started and idled at half speed. From this part on, all control of the rig by the driller

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Figure 1. General view showing draw works, swivel with mud-hose connections, hexagonal kelly, and rotary table

is from the four driller's speed master switches and the selector switch shown in Figure 3. To illustrate how the driller's control works, observe what the driller does to start a mud pump. An engine-generator set previously has been assigned, by means of the manual transfer switches, to supply power to this particular mud pump.

The driller moves the speed master switch handwheel from the off position which starts the mud pump. The further he moves the handwheel, the faster the mud pump runs. Up to approximately half motor speed, the engine remains at its half speed. As the driller calls for more motor speed by moving his speed master switch further, the engine automatically speeds. The driller does not have to touch the engine throttle, nor worry about overloading the engine. If the mud pump should become overloaded or even stalled, the load on the engine will be reduced so that the engine is not harmed. These functions are accomplished automatically by means of the engine governor and amplidyne control, which will be explained later.

If desired, the control equipment can be preset to limit the stalling torque on the motor from 75 to 150 per cent of normal motor torque. The engine may be operating at full speed and the mud pump suddenly stall, caused by a plugged bit at, let us say, 125 per cent of normal torque, regardless of where the driller's master switch may be. This torque limit adjustment is made at the control cabinet and not at the drillers position.

To stop the mud pump, the driller returns the master switch to the off position. The Diesel engine returns to idling, at half speed, and the mud pump motor stops.

The controls for all the other motors are the same. Reversing a particular motor merely requires the master switch to be returned to the off position, the handwheel pulled out and rotated as before. The motor reverses and accelerates in the opposite direction. Reversing is not required for mud pumps but is available.

Consider a few of the typical driller's operations.

"Spudding-in"

"Spudding-in" is a process of starting a hole and drilling it the first several hundred feet. There is not sufficient weight on the bit to make it bite at this stage. It is necessary for the driller to lift the drill stem a few feet and then drop it, thus giving the bit a fresh bite. Then it is rotated and may be done at the rate of several times per minute.

The driller has a common speed master switch for the draw works and the rotary table, as shown in Figure 3. It will operate either, but not both simultaneously. There is a "drill-hoist" selector switch which connects generators alternately to the rotary table or to the draw works, provided the speed control switch is in the off position.

The driller turns the drill-hoist selector switch to the *DW* position and turns the speed control master switch, raising the drill stem a little way. He then returns the master switch to the off position and declutches the motor from the hoist drum (the clutch is a pneumatically operated device) and lets the tool drop.

The drill-hoist selector switch is turned to the opposite position to *RT*, and the speed master is turned to rotate the table for a few revolutions. Then the process is repeated.

During this operation, one mud pump motor and engine set has been operating, probably at low speed, circulating mud. This engine set has been prevented from transferring in response to the drill-hoist selector switch by means of a selector switch on the control board.

Drilling

The "drill-hoist" selector switch is thrown to the drill position, which con-

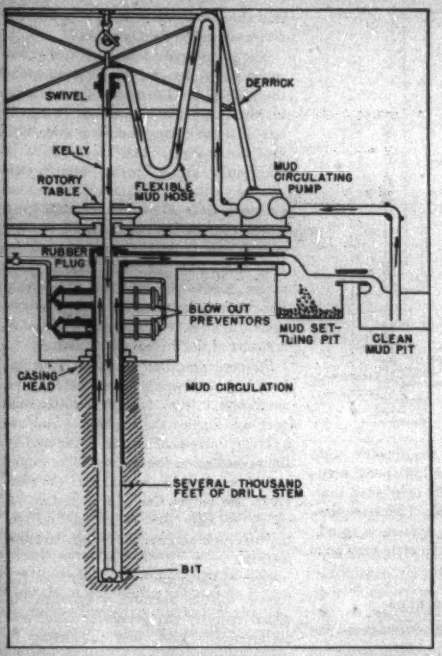

Figure 2 (left). Cross section of rig showing how mud pump circulates mud

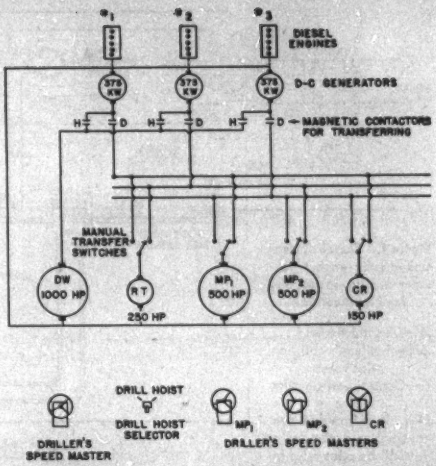

Figure 3 (above). Elementary power diagram of typical d-c drilling rig equipment

nects one engine set to the rotary table and another engine set to a mud pump. The third engine may be used on the second mud pump or it may be shut down.

The driller starts and runs the rotary table, at the desired speed with the speed master, and has no throttle control for the engines, since this is under the control of the engine governor.

Hoisting

When it becomes time to change the bit on the end of the drill stem, the mud pumps are shut down first and the flexible mud hose, swivel, and kelly assembly disconnected from the drill stem. Meanwhile, the engines are idling at half speed because all of the speed masters are in the off position.

The mud hose swivel and kelly (the square piece of drill stem that slides up and down in the square hole in the rotary table) then is dropped in the "rat hole." The "rat hole" is a spare hole that the driller thoughtfully has dug in advance for storing the kelly. It can be discerned in Figure 1.

The drill-hoist selector switch is thrown to the hoist position, which connects all of the engine-generator sets to the draw-works motor for maximum power. All of the engines are paralleled automatically and each may be loaded in accordance with its ability to carry load. The driller turns the speed master in accordance with the desired hoisting speed. If the string of drill stem is exceptionally heavy, the motor will slow down automatically to keep its input within the engine's ability, regardless of the speed-master position. If the drill stem should get stuck, the draw-works motor would stall at about 200 per cent torque or some less adjustable value without damage to the engines, generators, draw-works motor, or to the mechanical equipment, even if the speed master is in the maximum speed position. However, the driller should not let this condition persist for any period of time, since the thermal capacity of the draw-works motor does not permit it to develop 200 per cent torque continuously.

After the drill stem has been hoisted three lengths (a "thribble"), the driller returns his speed master to the off position and sets his hand brake. The drill stem remaining in the hole is wedged carefully into the rotary table. The driller then unscrews the withdrawn lengths of drill stem by holding the withdrawn portion with tongs and rotating the rotary table by power.

After the withdrawn drill stem section is stacked over in the derrick, the hook is driven down at high speed and light load to get another grip on the drill stem remaining in the hole. For this operation, the driller's speed master is pulled outward and turned as far as it will go to get maximum speed.

It may require several hours to take the drill stem out of the hole, attach a new bit, and lower it into the hole again, section by section. This process is called a "round trip."

In lowering a heavy load, however, the draw-works motor is declutched and the lowering energy is dissipated in a water-cooled brake. The Diesel engine cannot absorb very much energy and regenerative lowering has not been resorted to as yet.

In all this maneuvering, the driller needs pay no attention whatever to anything but his speed master and drill-hoist selector switch. All paralleling, speeding up, and slowing down of engines is entirely automatic. When they are paralleled, as on hoisting duty, there is no delicate adjusting of throttles to contend with or nursing of a smaller or defective engine. The automatic governors will make the engines take all the load of which they are capable, and no more, and make each engine parallel with the others.

Manually Selected Combinations

It may be necessary to shut down an engine-generator set for maintenance purposes or simply because its power is not needed. It is desirable, therefore, to give each main drive motor two choices of

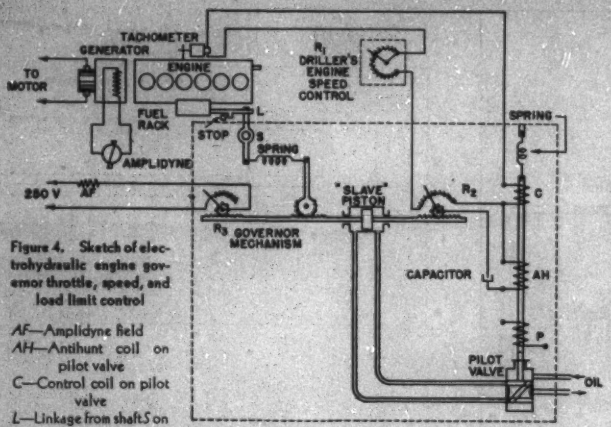

Figure 4. Sketch of electrohydraulic engine governor throttle, speed, and load limit control

AF—Amplidyne field
AH—Antihunt coil on pilot valve
C—Control coil on pilot valve
L—Linkage from shaft *S* on governor to engine fuel rack
P—Coil on pilot valve for paralleling engines
R_1—Driller's speed control rheostat
R_2—Antihunt rheostat
R_3—Rheostat load limit
S—Governor shaft for connection to fuel rack

engine-generator sets. This choice is provided by the manual transfer switches on the control panel.

A selector switch for each engine, located on the control panel, will take away control from the driller's drill-hoist selector switch so that an engine may be retained on some special duty, such as driving a mud pump for mud mixing even while hoisting.

Electrohydraulic Engine Governor

The internal combustion engine is essentially a constant-torque device over an adjustable speed range. It rapidly overheats when submitted to overloads with resultant increase in maintenance.

Since a drilling load is both intermittent and varying, it is highly desirable to run the engines only at the lowest speed consistent with the power required. This rate of speed saves both fuel and wear and tear on the engine. To appreciate this point, just imagine the maintenance and fuel consumption on an automobile engine if it is run always at top engine speed, and the car started and stopped at each traffic light with the clutch and gear shift. That procedure had been followed by the drilling industry with Diesel-electric drives up to the advent of the electrohydraulic governor.

The fuel injection system on most Diesels is such that at low speeds, full throttle opening will overheat the engines. That is, with the throttle wide open and the engine at low speed, actually more fuel per stroke is injected than at full rated engine speed. Thus a requirement of the governing system is to adjust automatically the throttle stop as a function of engine speed.

Functions of the Governor

The functions of the governor can be summarized as follows:

1. It measures engine speed and adjusts the engine throttle to maintain this speed up to permissible full throttle opening.
2. When the throttle is fully open and a further attempt is made to increase load on the engine, it automatically reduces the generator field.
3. It automatically adjusts the position of the throttle stop as a function of engine speed.

All these requirements are accomplished rather simply by the electrohydraulic governor. Refer to Figure 4.

An electric tachometer produces a d-c signal proportional to engine speed. This signal is put into a solenoid operated pilot valve. The pull of the solenoid *C* is balanced against a spring. A slight unbalance in engine speed thus permits the pilot valve to let in a little oil, under pressure, to one side or the other of a "slave" piston, which can move as far as necessary in adjusting the throttle to restore the engine speed and thus the balance between solenoid *C* and the spring.

These factors are the elements of any governing system. Since the slave piston has no restoring spring and can take up any position necessary to balance the solenoid *C* against the spring, the system is isochronous. This condition means that the system has no engine speed droop whatever as the load is applied.

The engine speed controller R_1 is a rheostat inserted between the tachometer and the solenoid *C*. The more resistance is cut in, the faster the engine has to run to establish the balance between solenoid *C* and the spring. The combination of pilot valve, "slave" piston, and throttle will see to that condition. Thus the engine will run at adjustable constant speed levels, depending on the position of rheostat R_1. It is usual to run the engines over either a 2/1 or a 3/1 ratio of speed range. The engine speed set by rheostat R_1 is entirely independent of the load the generator tries to put on the engine. R_1 is a part of the drillers speed master.

Suppose now the generator load has been increased slowly (or suddenly) until the "slave piston" has the throttle wide open and against the fuel stop. Suppose a further increment of load is imposed by the generator on the engine. The engine slows momentarily, unbalances the pilot valve and moves the "slave" piston. A spring between the "slave" piston and the fuel rack permits the former to move further.

This additional movement of the "slave" piston operates a rheostat R_3, which reduces the generator field, and therefore the load, just sufficiently to maintain engine speed.

Let us go back now to the instant where the load on the generator has just brought the throttle to full throttle position. If suddenly two cylinders cut out because of, for example, clogged fuel injectors, the engine will slow down momentarily and the "slave" piston will move. Since the fuel rack is already against the stop, the "slave" piston will simply reduce the generator field and thus keep the remaining cylinders fully loaded, but not overloaded. In this way the governor recognizes the engine's ability to take load. Refer to Figure 5 where this condition is illustrated by a generator curve.

With R_1 in the maximum engine speed position, the usual differential compound-wound generator volt-ampere characteristic for 100 per cent engine speed and 100 per cent field current is followed from no-load current up to point *X*. At this point the governor reaches the fuel stop, and the load limit rheostat R_3 shown in Figure 4 takes over and reduces the generator field. As more ampere load is put on the generator, R_3 makes the generator characteristic follow the load limit line shown in Figure 5, which is, of course, a constant kilowatt or horsepower load on the engine.

If a couple of cylinders were to cut out,

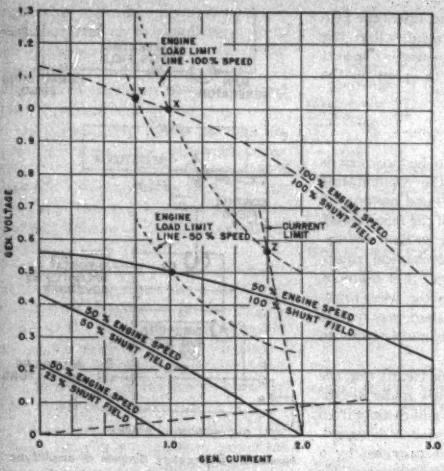
GEN. VOLTAGE
GEN. CURRENT
ENGINE LOAD LIMIT LINE - 100% SPEED
ENGINE LOAD LIMIT LINE - 50 % SPEED
CURRENT LIMIT
100 % ENGINE SPEED 100 % SHUNT FIELD
50 % ENGINE SPEED 100 % SHUNT FIELD
50 % ENGINE SPEED 50 % SHUNT FIELD
50 % ENGINE SPEED 25 % SHUNT FIELD
X
Y
Z

Figure 5 (left). Generator characteristics with electrohydraulic governor load limit and amplidyne current limit

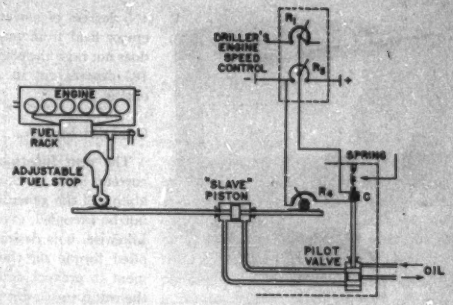

Figure 6 (above). Sketch of electrohydraulic engine governor showing mechanism for adjusting throttle stop as a function of engine speed

the fuel stop would be reached earlier at some such point as Y, and the generator volt-ampere characteristic would follow a constant kilowatt or horsepower curve below the other. Thus the governor automatically adjusts the load to suit the engine condition. This feature is very valuable as the engines get older and less able to carry the same load than when new and in good repair.

Of course, as the driller's engine speed control rheostat R_1 is moved, the whole voltage characteristic moves up and down, as shown in Figure 5.

Throttle Stop Positioning. As yet nothing has been said about adjusting the position of the throttle stop as a function of engine speed. This adjustment is done with a completely separate mechanism from that so far discussed. As shown in Figure 6, the fuel stop is adjusted by a "slave" piston and solenoid-operated pilot valve which are, mechanically, duplicates of those used for the fuel-rack control. This system simply positions the "slave" cylinder in response only to the position of the potentiometer rheostat R_3.

Rheostat R_4 is on the same shaft as the driller's engine speed control rheostat R_1, and, together, they constitute the driller's speed master.

Note that the "slave" piston drives a cam-shaped stop for the fuel rack. The shape of this cam is determined by the engine manufacturer's curve of speed versus maximum-fuel, which is not a straight line.

Any kind of servomechanism would serve as well as that shown to position the fuel-stop cam as a function of engine-speed rheostat position, but a solenoid-controlled pilot valve and "slave" valve are most convenient, since oil under pressure is already available in the governor. The parts are duplicates of those on the throttle control.

All the solenoid valves, "slave" pistons, fuel stops, oil pressure regulating valve, and rheostats R_3, R_5, and R_4 are housed in one frame and mounted on the engine, convenient to the fuel rack, as illustrated in Figure 7.

The antihunt circuit for the governor shown in Figure 4 consists of rheostat R_2, a capacitor, and an AH coil on the pilot valve. A movement of the "slave" piston transiently introduces a force in the pilot valve in the opposite sense. This stabilizing action is very effective.

Advantages of Governor

To recapitulate, the advantages of the electrohydraulic Diesel engine governor for d-c drilling rig equipments are as follows:

1. It automatically prevents overloads on the engine, thus removing one of the principal causes of engine wear and failure.

2. It provides engine speed control by the driller at a remote location by means of a very simple rheostat and electrical connections. It thus permits the driller to run the engines at the lowest speed consistent with the required drilling operation. This feature promotes both fuel economy and low maintenance.

3. Paralleling several engine-generator sets, as required by the draw-works motor, and controlling them from one driller's controller is very simply accomplished by mechanically paralleling the speed control rheostats R_1. Proper division of load among the several engine sets is provided automatically by the governors.

4. The governor provides a "wrap-around" or constant kw characteristic of the generator around the engine characteristic, as shown in Figure 5. This characteristic permits the maximum torque at the maximum speed of the drilling motors at all points within the ability of the engines, instead of only at one fixed point as with conventional 2- or 3-field generator characteristics. This feature is, in effect, an automatic gear shift providing a continuously adjustable choice of ratios between the engine and the driven load.

Amplidyne Control System

An amplidyne is used, instead of a conventional exciter, to excite and control the main generator field because the greater amplification factor of the amplidyne requires only a few watts for the amplidyne field. This factor makes possible the very small and extremely sturdy rheostats used in the governor (illustrated in Figure 7) and in the drillers speed master.

The first requirement of the control system is that the generator voltage be manually controlled and adjusted in either direction. The principles of this system are shown in Figure 8.

The driller's control rheostat R_4 is a potentiometer across a source of d-c control power. A potential V_3 from the potentiometer R_4 is compared with a potential V_1 through the main amplidyne control field F_1F_3. Note that V_1 is a potential drop across a resistor A in the

Figure 7. An electrohydraulic governor (tachometer not shown)

main generator field. Thus movement of the driller's rheostat R_4 adjusts the main generator field, and, as a result, the generator characteristics of Figure 5 for different values of generator field current are obtained. The very high amplification factor of the amplidyne makes V_1 always very nearly equal to V_3.

A set of forward and reverse contactors are actuated by pulling out the driller's master switch handle before rotating it, giving forward or reverse generator field excitation.

Instead of comparing the voltage V_3 with main generator field current, it might have been compared directly with the main generator voltage. However, if this were done, the amplidyne would try to nullify the action of the generator differential series field. Each time the main generator differential series field tried to pull the voltage down, the amplidyne would try to pull it up. Also, as has been proved by many types of installations, the stability of the system is much better if the control potential V_3 is balanced against main generator field current, leaving the differential series field to do its duty.

The engine load-limit potentiometer rheostat R_2 is inserted between the driller's control rheostat R_4 and the amplidyne control field F_1F_2, and is the same governor-actuated rheostat R_3 as shown in Figure 4.

Since several generators are to be controlled in parallel from one driller's control master switch, when hoisting, several amplidyne fields can be paralleled on one R_4 rheostat.

The potentiometer R_6, shown in Figure 8, and the engine speed control rheostat R_1 (Figure 4) are on one shaft and form the complete drillers speed master. The complete travel of the drillers speed master is about 330 degrees. The first 165 degrees of movement raises the generator field from zero to full value, but does not raise the engine speed. The next 165 degrees cut in R_1 to speed up the engine.

Current Limit

The next function to be provided is current limit so that the commutating ability of the generators and motors will not be exceeded, even if the motors stall. Likewise, it is desirable to limit the applied torque on the mechanical equipment to prevent damage. For example, the rotary-table-drive motor, when rotating a long string of drill stem, may require a definitely limited maximum torque to prevent twisting it off.

It should be understood clearly that the current limit function now under discussion is entirely separate and distinct from the engine load limit previously discussed. Current limit control is provided by a separate field on the amplidyne. This control field F_5F_6, illustrated in Figure 9, always is excited in the opposite direction from the control field F_1F_2 and must overpower it, and thus reduce main generator excitation whenever the main generator current reaches a certain value.

The current limit must be ineffective until a certain selected value of current is reached, regardless of the direction of flow of that current, and be effective when that value is reached.

In Figure 9 is shown the elementary diagram of the amplidyne connection used to accomplish this function.

A pair of rheostats R_7 are placed across a source of d-c control power. This reference voltage is compared, through a pair of blocking selenium rectifiers, to the drop across the commutating and series fields, which is proportional to generator current.

For one direction of main generator current, V_3 must be greater than V_4 before blocking rectifier BR_1 will permit current to flow in current limit field F_5F_6.

When the generator current reverses, which depends on a reversal of the control field F_1F_2, the drop V_4 is in the opposite direction. When V_3 exceeds V_4, the blocking rectifier BR_2 permits current to flow in the current limit field F_5F_6 in such a direction as to oppose control field F_1F_2.

The effect of current limit control is shown in Figure 5. The cut-off point Z can be adjusted for any desired value of current by adjusting rheostat R_7. While current limit begins to cut off at the control setting of point Z, the generator current has to rise a further 10 or 15 per cent

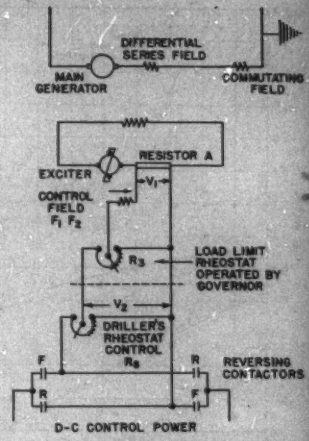

Figure 8. Elementary diagram of amplidyne field and engine load limit control

before the current limit field F_5F_6 can overcome completely the control field F_1F_2 and bring the generator voltage to zero.

Antihunt and Paralleling

An antihunt field F_7F_8 is provided on the amplidyne so that any sudden rise of amplidyne voltage causes a transient current to flow through the capacitor and control field F_7F_8, which opposes the change.

A paralleling field F_9F_{10} is connected, as shown, and connects to a similar arrangement on any additional generators connected in parallel. It tries to make the generator divide the loads and operates exactly by the same manner as a paralleling connection on regulators.

The paralleling field F_9F_{10} shown in Figure 9 is quite weak in comparison with the other fields and is mainly effective at light generator loads or for very sudden transients (for example, one generator out of several in parallel suddenly losing its field). Paralleling field F_9F_{10} is completely overcome and supplanted in function whenever the load limit feature of the governor goes into action.

Auxiliary Drives

In addition to the main drive motors, there are a number of auxiliary motors for driving ventilating blowers, pumps, air compressors, shale shakers, blowout preventer, and bug fans. The require-

ments for such motors may total 50 or 60 horsepower on a typical rig. Also, six or seven kilowatts is required for adequate lighting. Approximately 15 kilowatts of excitation power is required for the main drive motors.

On Diesel-electric rigs, it has been the practice in the past to add a constant potential d-c auxiliary generator to each engine. A typical rating is 30 kw, 125 volts d-c (125 volts has been selected in the past because of the lighting requirements).

Because the main engines are usually started by compressed air, a small battery-started gasoline engine-driven generator of five or ten kilowatts is installed to supply power to the air compressor motor, when the main engines are down, and to supply lighting power when rigging up or tearing down the rig.

This almost universal practice of supplying 125-volt d-c auxiliary power requires expensive d-c auxiliary motors and d-c control, generally with explosionproof enclosures.

Since the auxiliary drives require only constant-speed motors, a-c auxiliary power is recommended. This a-c power permits very simple sturdy control and the auxiliary motors to be squirrel-cage induction motors, explosionproof if desired.

A very careful analysis of the costs of d-c versus a-c auxiliary power reveals that the cost of auxiliary equipment for a-c power is about 25 per cent cheaper than for d-c power. In making this comparison, two full capacity engine-driven 440-volt, 3-phase 60-cycle alternators were included. One of these alternators is a complete spare to the other, since the entire rig depends on this auxiliary power being available.

The cost comparison includes the cost of two auxiliary engines, but takes credit for eliminating the small 5-kw emergency lighting engine generator and reducing the size necessary for the main engines.

The use of entirely separate engine-driven auxiliary power generators is made even more desirable by the use of adjustable speed main engines. If d-c auxiliary power generators are driven by the main engines, they have to give full output at the lowest engine speed. This condition increases the cost of such d-c auxiliary equipment, and the foregoing cost comparison was made on the basis of running the main engines over a two to one speed range. With a-c auxiliaries, the lighting circuits are standard 115 volts, stepped down from 440 volts by transformers.

The advantages of a-c versus d-c auxiliaries can be summarized as follows:

1. About 25 per cent reduction in first cost.

2. The main engine-driven-generator units are simplified, lighter, easier to move and set up because of the elimination of the top-mounted belt-driven constant-voltage d-c auxiliary generators, and the consequent reduction in size of the main engine required.

3. The main control panel is reduced in size and weight because of simpler a-c instead of d-c control for auxiliaries.

4. Auxiliary a-c power at 440 volts, 3 phase, requires smaller cable to distribute power than does 125 volts d-c.

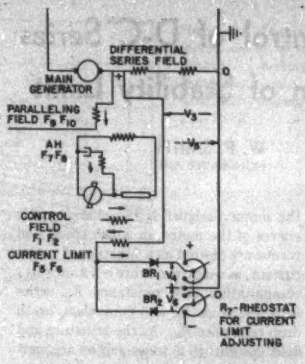

Figure 9. Elementary diagram of amplidyne control showing current limit, antihunt, and paralleling fields

The disadvantages of having two small 100 or 125 horsepower internal combustion auxiliary engines to maintain are more than overcome by not having to run the main engines when only auxiliary power is required. Also, the 5- or 10-kw engine-driven set is eliminated.

Ventilation

The main rig motion motors are usually force-ventilated because they frequently are required to operate at very low speeds and full torque. Also, it is desirable to bring in fresh air, free from explosive gas mixtures, to eliminate the explosion hazard which would otherwise be present when the well strikes gas.

The most usual method of ventilation is to mount a small motor-driven blower on the top of each main d-c motor and run a duct away from the derrick to a safe source of fresh air.

These ducts have been made of steel in the past and are considered a nuisance to tear down and move approximately every two months. There is now a probability of obtaining flexible rubberized non-collapsible ducts which will be very easy to move.

The generators are self-ventilating and are located away from the derrick in a nonhazardous area.

On barge-mounted rigs, there is usually a central blower system, and air is piped to the various motors.

Because of the duty on the coring-reel motor, it usually can be totally enclosed and one-hour rated, thus eliminating the cumbersome duct work. However, to make this large totally-enclosed motor truly explosionproof would be very expensive, but it is a very simple matter to infiltrate a very small amount of safe air from the compressor system to keep this motor purged and under slight pressure.

Frequently, the mud pumps are located far enough away from the rig so that no duct work is necessary to bring in safe air, and their blowers take air directly from the ambient surroundings.

References

1. Electric Equipment on Rotary Drilling Rigs, G. R. Prout. *Petroleum Engineer*, May 1940.

2. Amplidyne; A New Tool of Many Uses, F. Mohler. *Iron and Steel Engineer*, September 1940.

3. Fundamental Principles of Amplidyne Applications, F. E. Crever. AIEE Transactions, volume 62, 1943, September section, pages 609–06.

4. Industrial Applications of Amplidyne Generators, D. E. Shoults, M. A. Edwards, F. E. Crever. *General Electric Review*, volume 43, 1940.

5. Steady-State Theory of the Amplidyne Generator, T. D. Graybeal. AIEE Transactions, volume 61, 1942, October section, pages 750–6.

6. Modern Rotary Drilling Machinery and Practices, W. S. Crake. *Oil and Gas Journal*, July 7 to August 18, 1945.

7. New 2,100 Horsepower Diesel-Electric Drilling Rig Is Compact and Portable, K. Marshall Fagin. *Petroleum Engineer*, August 1945.

8. Practical Features of Diesel-Electric Rig in Service, J. E. Brantly. *World Petroleum*, May 1938.

9. Deep-Well Drilling With Direct Current, L. D. Sanderob, P. L. Savage. *Petroleum World*, September 1942.

10. Direct-Current Rigs for Deep-Drilling Operations, R. A. J. Dawson. *Petroleum Engineer*, August 1943.

11. Variable Voltage Equipment for Rotary-Drilling Rigs, E. H. Lamberger. AIEE Transactions, volume 59, 1940, April section, pages 248–56.

12. Diesel-Electric Rigs in Gulf Coast Service, Orville Adams. *Petroleum Engineer*, June 1941.

13. New Diesel-Electric Rig, Arch Rowan. *Oil Weekly*, October 7, 1935.

14. Electric Power for Drilling in Jungle or Desert, W. G. Taylor. *World Petroleum*, May 1936.

15. Parallel Operation of Main-Engine-Driven 400-Cycle Aircraft Generators, L. O. Lewey, Jr. AIEE Transactions, volume 64, 1945, December section, pages 811–16.

16. Governor for Variable-Ratio Transmission Used in Developmental 400-Cycle Electrical System for Large Aircraft, P. F. Dosch, D. E. Garr, J. G. Hutton. AIEE Transactions, volume 65, 1946, April section, pages 194–8.

Dynamic Braking Control of D-C Series Motors—Calculation of Stability Limit

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Synopsis: This paper presents an extension of the conventional method of calculating speed-torque curves for d-c series motors used with dynamic braking controllers, which permits determination of the stability limit with overhauling loads such as occur on crane hoists. It is shown that such stability limit can be increased by the addition of series resistance.

IN laying out control equipment, the design engineer looks for methods which enable him to calculate, with a minimum of effort and with reasonable accuracy, the speed-torque curves obtained on various controller points. Direct-current series motors are widely used for heavy duty intermittent drives, such as cranes, hoists, ore and coal unloaders, and other material handling equipment. Control of such motors is obtained by inserting resistance in the various branches of the motor circuit, that is, the armature and the field.

Considering that commercial resistors may deviate as much as ten per cent from their rated resistance, that line voltage may vary by ten per cent or even more, and that it is difficult on most motor applications to predict actual load conditions within a few per cent, it does not appear necessary to forecast motor performance with a greater accuracy than a few per cent. It is of greater importance to have a method available which permits making approximate calculations quickly so that control systems can be compared and analyzed without spending an undue amount of time and effort.

A simple method of calculation which is widely used by design and application engineers has been described by A. A. Merrill.[1] The information required from the motor designer is the characteristic curves of the motor, in which speed and torque are plotted as a function of motor current, as well as armature resistance R_a, commutating field resistance R_c, series field resistance R_f, and equivalent brush drop resistance R_b. As the armature and field current of a series motor are normally the same, all values entering into the calculations can be expressed in terms of either field or armature current.

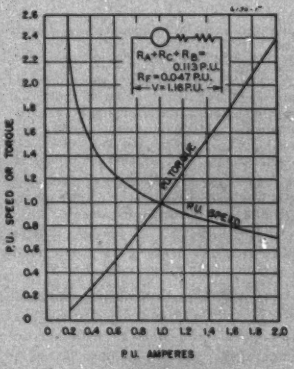

Figure 1. Per unit characteristic curves of d-c series motor

Average of line of 30-minute-rated mill motors

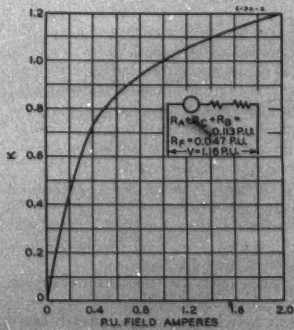

Figure 2. Factor K, calculated from Figure 1, as a function of field current

To obtain results which are generally applicable to motors of various sizes, it is convenient to express operating quantities in "per unit" (pu), rather than in actual numerical values. Rated or normal values are called base values, expressed as unity, and all other values are expressed as a decimal fraction of the base values. Base quantities used in this paper are defined as follows:

base current = rated full load current
base torque = rated full load torque
base speed = rated full load speed
base voltage = generated armature electromotive force at rated torque and rated speed
base resistance = base voltage divided by base current
base flux = flux per pole at rated full load speed and current

Figure 1 represents the average characteristic curves of a line of 30-minute-rated mill type d-c series motors. All values are expressed in per unit, based on rated 30-minute load. The actual load expressed by base current or base torque is higher than the same machine would be required to carry if it were rated on a continuous basis. Consequently, the magnetic and electric loadings are high, and the effects of saturation and armature reaction are more noticeable than for continuous rated machines of similar physical size, when loads are expressed in per unit, based on rated values.

Conventional speed-torque calculations are based on two fundamental equations for dynamo electric machines which state that

$$S = \frac{E}{k_s \phi} \tag{1}$$

and

$$T = k_t \phi I_a \tag{2}$$

where

E = generated voltage
T = developed torque
ϕ = magnetic flux per pole
I_a = armature current
S = speed of rotation
k_s and k_t = constants, the value of which is determined by motor design and by the units of E, R, I_a, and S

Let

$k_s \phi = K_s$ and $k_t \phi = K_t$

Then

$$S = \frac{E}{K_s} \tag{3}$$

and

$$T = K_t I_a \tag{4}$$

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The authors wish to acknowledge the assistance given them in the preparation of this paper by C. W. Lange, engineer, d-c armored motor engineering division, General Electric Company, who first called attention to the effect of series resistance on the stability limit.

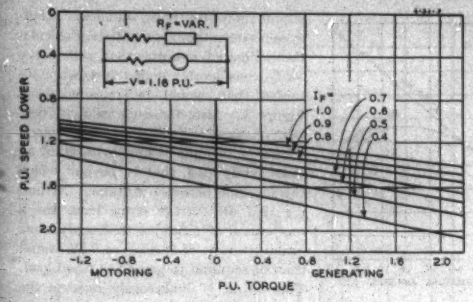

Figure 3. Speed-torque curves of a dynamic braking controller, calculated with constant K

In the per unit system, $K_{s(pu)}$ and $K_{f(pu)}$ have the same numerical value because they are both directly proportional to the magnitude of the flux. This may be shown as follows:

$$K_{s\,base} = \frac{E_{base}}{S_{base}} = k_s\phi_{base}$$

$$K_{sl} = k_s\phi_1$$

$$K_{s(pu)} = \frac{K_{sl}}{K_{s\,base}} = \frac{k_s\phi_1}{k_s\phi_{base}} = \frac{\phi_1}{\phi_{base}}$$

$$K_{f\,base} = \frac{T_{base}}{I_{a\,base}} = k_f\phi_{base}$$

$$K_{fl} = k_f\phi_1$$

$$K_{f(pu)} = \frac{K_{fl}}{K_{f\,base}} = \frac{k_f\phi_1}{k_f\phi_{base}} = \frac{\phi_1}{\phi_{base}}$$

Therefore

$$K_{s(pu)} = K_{f(pu)} = K \qquad (5)$$

Also

$$K_{s(pu)} = \frac{E_{(pu)}}{S_{(pu)}} \qquad (6)$$

and

$$K_{f(pu)} = \frac{T_{(pu)}}{I_{a(pu)}} \qquad (7)$$

Therefore:

$$K = \frac{E_{(pu)}}{S_{(pu)}} \qquad (8)$$

or

$$K = \frac{T_{(pu)}}{I_{a(pu)}} \qquad (9)$$

and

$$S_{(pu)} = \frac{E_{(pu)}}{K} \qquad (10)$$

$$T_{(pu)} = KI_{a(pu)} \qquad (11)$$

Values of K may be calculated from Figure 1 by equation 8 or 9. When equation 8 is used, $E_{(pu)}$ is obtained from the equation

$$E_{(pu)} = V_{(pu)} - I_{a(pu)}R_{a(pu)} \qquad (12)$$

where

$V_{(pu)}$ = per unit line voltage
$I_{a(pu)}$ = per unit amperes in armature circuit
$R_{a(pu)}$ = per unit ohms in armature circuit

For generator operation, $E_{(pu)}$ is given by

$$E_{(pu)} = V_{(pu)} + I_{a(pu)}R_{a(pu)} \qquad (13)$$

The data so calculated are then plotted against field amperes as illustrated by Figure 2. The data shown in Figure 2 are based on values and curves given in Figure 1.

Speed and torque for any given set of conditions can be calculated using Figure 2. When field current, armature current, line voltage, and motor resistance are known, generated voltage is calculated by equation 12 for motor operation, or equation 13 for generator operation. Speed is then obtained from equation 10, and developed torque from equation 11, using the value of K corresponding to the given field current. The shaft torque may be obtained by multiplying the developed torque by torque efficiency for motor operation, or dividing the developed torque by torque efficiency for generator operation. In subsequent speed-torque calculations, torque efficiency is considered to be unity.

A family of speed-torque curves for a dynamic braking controller, calculated by the method described above, is given in Figure 3. In this type of controller, the series motor is connected as a shunt machine on lowering points. Heavy loads overhaul the motor, which acts as a shunt generator and develops a dynamic braking torque restraining the load. This torque is indicated as positive in Figure 3. An empty hook or a light load is driven down by the motor, which acts as a shunt motor, delivering a torque to accelerate the load. This torque is indicated as negative. Line voltage used for the calculation is 1.16, total internal motor resistance being 0.16.

The calculated curves of Figure 3 show that any desired no-load speed can be obtained by inserting sufficient resistance in series with the field. The straight-line curves give the impression that speed varies only slightly within the operating range between motoring and generating. This conclusion is incorrect. J. A. Jackson[2] has called attention to the fact that when operating with weakened field, the motor develops less dynamic braking torque than the curves of Figure 3 indicate. As braking torque and armature current increase, armature reaction plays an important role, reducing the effective flux. For a given overhauling torque, the speeds are higher than the calculation indicates. There is a definite limit of dynamic braking torque which the machine can develop with a given

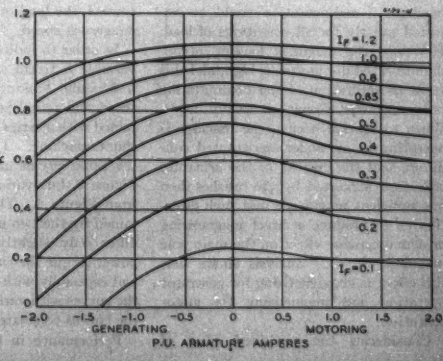

Figure 4. Factor K for d-c machine operating as motor or generator

Average of line of 30-minute-rated mill motors

amount of field current. If the load exceeds this torque, the machine becomes unstable, and a runaway condition results. To calculate the actual performance and the stability limit, it is necessary to abandon the concept that K is an independent function of field current.

Stability Limit

To obtain a true picture of the variation in the value of K with variation in armature current, it is necessary to test the motor over a range of loads both motoring and generating at several different values of field current. The average results, expressed in per unit values, of a number of such tests on a line of mill type d-c series motors are given in Figure 4. It has already been shown that the value of K is directly proportional to the magnetic flux in the motor, and it is evident from the curves of Figure 4 that the magnitude of the armature current does materially influence the amount of magnetic flux. This influence is the result of two factors:

1. Demagnetization produced by cross-magnetizing armature reaction.

2. Magnetization or demagnetization produced by currents flowing in armature coils undergoing commutation.

The theory of demagnetization produced by armature reaction may be found in any textbook on d-c machinery. In brief, the cross-magnetizing reaction produces a distortion in the flux distribution between the main poles and the armature which, because of the characteristic shape of the saturation curve, results in a net loss of flux. The effect is the same whether the machine is operating as a motor or as a generator.

The magnetizing or demagnetizing effect produced by current in the armature coils undergoing commutation would not be noticeable in a commutating pole machine if compensation could be adjusted exactly for all conditions of load. However, the magnetic loading of 30-minute-rated d-c motors is high, and this leads to saturation of the commutating pole magnetic circuit at heavy loads. When saturation occurs, the machine is operating in an undercompensated condition, and the current in the armature coils short-circuited by the brushes then has sufficient magnitude and such direction as to produce a direct magnetizing or demagnetizing effect on the main pole magnetic circuit. Analysis shows that this effect is demagnetizing for generator operation and magnetizing for motor operation.

Considering the combined effect of these two phenomena, it will be noted that they are additive and demagnetizing for generator operation. It is to be expected that the result would be an appreciable loss of flux, and the test results presented in Figure 4 confirm this expectation. For motor operation the two effects are opposing, and the loss of flux at heavy overloads is much less, particularly at very heavy and very light field currents where the effect of cross-magnetizing armature reaction is minimum.

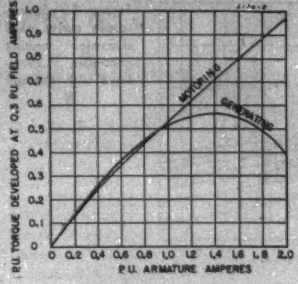

Figure 5. Developed torque, motoring and generating

The loss of flux with increasing armature current when operating as a generator results in very definite torque limitations. Equation 11 states that developed torque is equal to the product of K and armature current. Since K is an inverse function of armature current for generator operation, the product has a definite maximum value, as illustrated by Figure 5. It is the maximum value of torque which determines the limit of stable operation. When it is exceeded, even under transient conditions, dynamic braking control is lost and cannot be regained, because increase in speed corresponds to decrease in torque. With loss of braking control, the load quickly accelerates to a dangerous speed.

In order to indicate the significance of variable K to the speed-torque curves of a dynamic braking controller, Figure 6 shows the actual performance curves obtained with a series motor, connected as a shunt machine. These curves apply to the same circuit and field conditions as Figure 3, but variable K has been used from Figure 4. The no-load speeds obtained by the two methods of calculation differ only slightly. In the region of power torque the curves differ somewhat, and especially with weak field the slope of the curves with variable K is less than for the curves calculated with constant K.

Performance in the dynamic braking region shows the most significant difference between the two methods of calculation. Figure 6 indicates that, with heavy loads, considerably higher speeds are obtained than would be expected from Figure 3. Also, for each value of field current, there is a definite torque beyond which the machine is unable to retard an overhauling load, that is, beyond which the machine becomes unstable. Assuming that an average crane hoist has a mechanical efficiency of 0.85, a dynamic braking torque of $(0.85)^2$, or 0.72, would then be required to lower full rated load. This torque is dangerously close to the motor stability limit with a field current of 0.5 or less.

Speed-torque curves such as plotted in Figure 6 represent steady-state operating conditions. While switching between controller points, transient armature current peaks and corresponding torque peaks occur. Even though the steady-state stability limit may be greater than full-load torque, switching transients may cause the stability limit to be exceeded, resulting in a runaway condition. This means that the control designer is not free to select any no-load speed he can obtain by field weakening. The amount of field weakening which is permissible, and thus the no-load speed which can be realized, are definitely limited by motor stability when lowering full load.

Effect of Series Resistance

A simple method of increasing the stability limit is to insert a block of resistance in series with the parallel circuit formed by the armature and the field. Resistance between 0.10 and 0.20 has only a slight effect on no-load speed and on the slope of the curves in the motoring quadrant. In Figure 7 a set of speed-torque curves is plotted for the same circuit conditions as in Figure 6, except that series resistance of 0.15 has been added. For each curve the amount of resistance in series with the field is held constant at such a value that the indicated value of I_f would be obtained if R_s were zero. On each curve there is a point at which no current is taken from the line, and at this point the indicated value of I_f actually flows through the field, whereas under all other operating conditions field current is either somewhat smaller or larger.

Series resistance has the effect of changing the distribution of current between field and armature at any given operating point. In the range of motoring and light overhauling torques, field current is smaller than it would be without series resistance. This is of no practical conse-

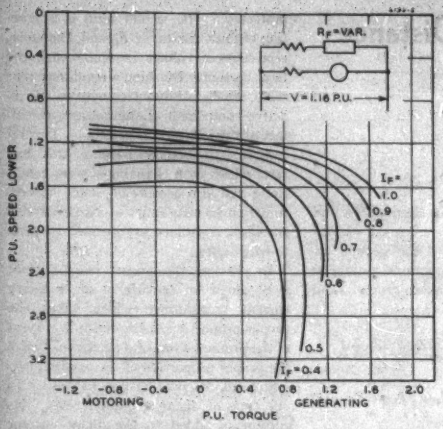

Figure 6. Speed-torque curves of a dynamic braking controller, calculated with variable K from Figure 4

No series resistance

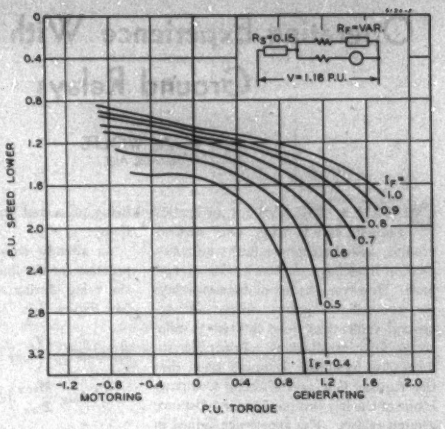

Figure 7. Speed-torque curves of a dynamic braking controller, calculated with variable K from Figure 4

With series resistance

Values of field current I_F indicated on curves exist only for the condition that line current is zero. Field resistance R_F for each curve is the same as in Figure 6

quence, as this is a stable motor operating range. Under high overhauling load conditions, however, the field current is greater. As factor K increases correspondingly, the motor is able to develop a higher braking torque, and the stability limit occurs at higher load. Comparing Figure 7 with Figure 6 for each value of field current, the slope of the curve is decreased in the higher torque region.

Assuming that the controller design permits transient torque peaks of twice normal when switching between controller points, the stability limit should occur at a braking torque of not less than twice the torque required to lower rated full load on the hook, that is, $2 \times 0.72 = 1.44$. Without series resistance, a field current of 0.70 would result in a runaway. With series resistance, a field current of 0.60 (at zero line current) would still be permissible.

Conclusions

The method of calculating speed-torque curves by using a variable factor K can be used for any d-c series motor for which sufficient test data are available for determining K both for motoring and generating operation. While the per unit data given in this paper permit the calculation of performance curves for the purpose of comparing various control circuit designs, actual motor test data may vary over a considerable range and must be used to determine the performance of any given motor application.

In designing dynamic braking controllers, using the motor field with suitable resistance in parallel with the armature, resistance in series with the parallel circuit formed by field and armature should be used to increase the motor stability limit.

References

1. The Speed-Torque Curves of a Series Motor, A. A. Merrill. *General Electric Review*, October 1933.

2. D-C Crane Equipment for Modern Steel Mill Cranes, J. A. Jackson. *Iron and Steel Engineer*, October 1938.

Operating Experience With Distance Ground Relays

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DISTANCE RELAYS for protection against wire-to-wire, two wire-to-ground, and three phase faults on transmission lines have met with wide acceptance. However, the use of distance relays for protection against single wire-to-ground faults has been limited to relatively few installations. From the information available, it would seem that the Kansas Gas and Electric Company is one of the few companies using distance ground relays. The experience gained in the use of these relays over the past seven years has demonstrated their reliability and good operating performance.

Theory of Distance Ground Measurement

The theory of distance ground measurement was first presented in 1931.[1] In general, distance relays compare the magnitude of a voltage with that of a current, the ratio being an indication of the distance to the fault. Zero sequence current and voltage (usually associated with ground relaying) are not suitable for distance ground relaying, because a comparison of these quantities is not a measure of the distance to the fault. The zero sequence voltage at the relay is equal to the sum of the zero sequence voltage drops from the relay to the source of ground current, and not from the relay to the fault as is required in distance relaying. Instead of these quantities, distance relays for ground faults use phase-to-ground voltage with the current in the corresponding phase, thus requiring three relays for the protection of each 3-phase line. This number is in addition to the relays required for protection against phase faults. For correct distance measurement under all system conditions, reactance type relays must be used and suitable compensation must be applied. The compensation used involves the zero-sequence current in the line section being protected and in the parallel line, if any.

As already shown,[1,2] the general expression for the line-to-ground voltage at the relay during a line-to-ground fault (see Figure 1) is

$$E_{aG} = mZ_{1GH}\left(I_{aGF}+I_{0GF}\frac{Z_{0GH}-Z_{1GH}}{Z_{1GH}}+I_{0GH}\frac{M_{0GH}}{Z_{1GH}}\right)+(I_{aGF}+I_{aHF})R_G \quad (1)$$

where

E_{aG} = line-to-ground voltage, A phase at G
m = fraction of distance from G to H at which fault is assumed to occur
I_{aGF} = phase A fault current in faulted line at G
I_{0GF} = zero-sequence fault current in faulted line at G
Z_{1GH} = positive-sequence impedance, station G to H
Z_{0GH} = zero-sequence impedance, station G to H
M_{0GH} = zero-sequence mutual impedance between the two parallel lines from G to H
I_{0GH} = zero-sequence fault current in parallel line
I_{aHF} = phase A fault current from opposite end of faulted line
R_G = fault resistance
G = substation where relaying is considered
H = substation at opposite end of line section
F = fault location

Looking at equation 1, it will be observed that if we could obtain a single current for the relay equal to the current expressed within the first brackets, namely

$$I_{relay} = I_{aGF}+I_{0GF}\frac{Z_{0GH}+Z_{1GH}}{Z_{1GH}}+I_{0GH}\frac{M_{0GH}}{Z_{1GH}} \quad (2)$$

we obtain a very simple result, as follows:

$$Z_R = \frac{E_{aG}}{I_{relay}} = mZ_{1GH}+\left(\frac{I_{aGF}+I_{aHF}}{I_{relay}}\right)R_G \quad (3)$$

where:

Z_R = impedance indicated by the relay
I_{relay} = current through relay

The first term of this expression is directly proportional to the distance from the fault to the relay and is independent of conditions external to the section being protected. The second term is a function of fault resistance R_G and, therefore, represents a voltage in phase with the fault current. By using a reactance type relay, which is responsive only to the reactive component of the voltage, the effect of the last term is rejected. This rejection is necessary because this last term varies with changing system conditions, and also because R_G itself is likely to vary over wide limits as compared with the fault resistance experienced in wire-to-wire faults.

In practice the proper relay current is obtained by the use of an auxiliary current transformer which takes the proper proportion of the residual current of the protected line and combines it with the proper proportion of the residual current from the parallel line (if any). In one type of distance ground relay, this current is added to the phase current I_{aGF} (equation 2), and the total fed into the relay. In another type of distance ground relay, the phase current I_{aGF} is fed into one winding of the relay, and the output of the auxiliary current transformer is fed into a second winding of the relay. Both windings then operate on the same element. The net result is the same.

A vector diagram of the currents and voltages involved in distance ground relaying is shown in Figure 2. In one type of distance ground relay, instead of using the voltage 90 degrees from the faulted phase for polarizing the directional element, as shown, residual or zero phase sequence current and voltage is used in the directional element.

Figures 5 and 6 show examples of typical installations of distance phase and ground relays.

Figure 7 is a typical wiring diagram for an installation of one type of distance ground relays. The phase relays are not shown.

Reasons for Use

There are several reasons why distance ground relays were considered justified and installed on the Kansas Gas and Electric Company system instead of ordinary directional ground relays or carrier pilot relays. The reason why Peterson coils could not be used also is explained.

Distance ground relays give the same high speed protection against ground faults that distance phase relays give against phase faults. Each line section is protected selectively without cascading settings. Although, in general, it is not necessary to cascade the settings of directional ground relays to anything like

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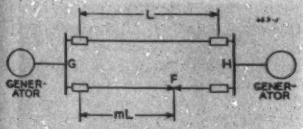

Figure 1. One-line diagram of assumed system

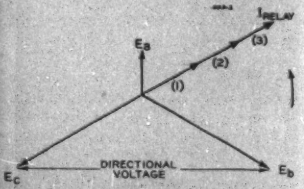

Figure 2. Vector diagram showing relation of currents and voltages for a one-wire-to-ground fault on phase A; I_{relay} = total of three components, namely:

(1). I_{aoA} = current in phase A

(2). $I_{aoA}\frac{Z_{aoB}-Z_{aoH}}{Z_{aoH}}$ = a percentage of the zero-sequence current in the protected line

(3). $I_{aoB}\frac{M_{aoH}}{Z_{aoH}}$ = a percentage of the zero-sequence current in the parallel line

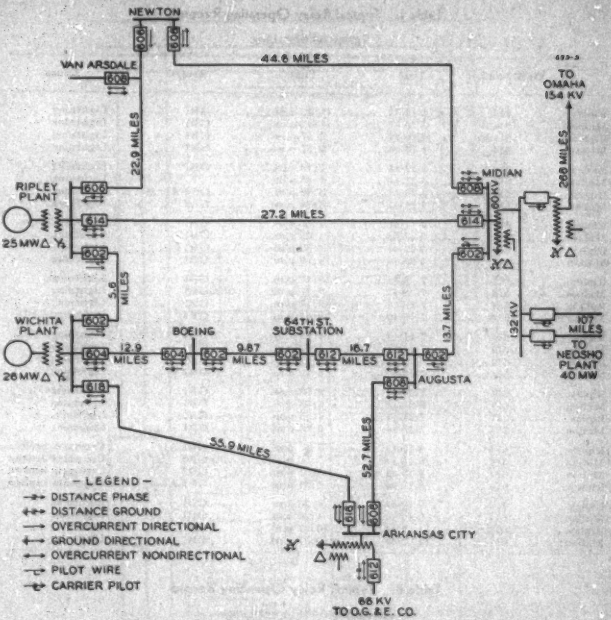

Figure 3. Central Kansas 60-kv system of the Kansas Gas and Electric Company

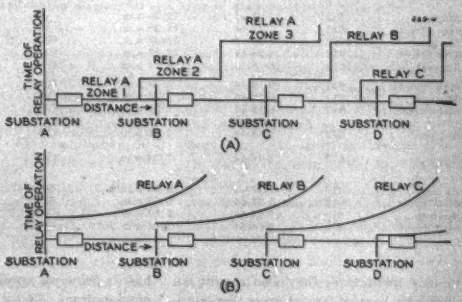

Figure 4

A—Distance relay characteristic, all but last 10 or 15 per cent of line is instantaneous trip

B—Induction relay characteristic

the extent necessary in the case of conventional overload phase relays, high speed distance ground relays do offer a very substantial saving in relaying time in most cases. This fact is especially true where there are a number of stations between grounding points, as on the loop between Wichita Plant and Midian, by way of 64th Street substation and Augusta (see Figure 3). The time saving to be gained by the use of distance relays instead of induction type ground relays is illustrated in Figure 4.

A very high percentage of all line faults on the Kansas Gas and Electric Company's 60-kv system are one wire-to-ground. For example, out of 451 "trip-outs," which have occurred on circuit breakers relayed with distance ground relays since their installation, 378 (83.8 per cent) were one wire-to-ground and 73 involved more than one wire.

Although the shock to the system is less severe for single wire-to-ground faults than for faults involving more than one wire, the large percentage of ground faults was considered justification for an expenditure for ground relaying equal to that for phase relaying.

Ground faults, when not cleared rapidly, frequently result in burned down conductors or overhead ground wires.

The cost of an installation of phase and ground distance relays is approximately half the cost of a carrier pilot relay installation. This cost makes complete distance relay protection for all types of faults very attractive in those cases where good relaying is desired, but where there exists no real necessity for going to carrier relaying.

It was not feasible to consider the use of Peterson coils on this system because of its complexity and number of grounding points. But, the main reason was that at Midian and Arkansas City (Figure 3) large autotransformers are used having graded insulation and solidly grounded neutrals which could not be isolated from ground by a Peterson coil.

Disadvantages

Distance ground relays have the disadvantage of being more complicated than distance phase relays. They require a set of auxiliary blocking relays, which block operation upon the occurrence of wire-to-wire or two wire-to-ground faults, in order to prevent overreaching into the next line section on these types of faults. As pre-

Table I. Typical Relay Operating Record

Ripley Midian Line

	OCB Number	Date	Time	Relays	Cause
Ripley	614	3-15-44	11:42 a.m.	GB1	Lightning
Midian	614	3-15-44	11:42 a.m.	GB1	Lightning
Ripley	614	4-10-44	9:57 p.m.	GB1	Lightning
Midian	614	4-10-44	9:57 p.m.	GB1	Lightning
Ripley	614	4-22-44	1:46 a.m.	GB1	Lightning
Midian	614	4-22-44	1:46 a.m.	?	Lightning
Ripley	614	4-23-44	3:38 p.m.	GA1-A1	Lightning
Midian	614	4-24-44	3:38 p.m.	GA2	Lightning
Ripley	614	5- 1-44	1:02 a.m.	GB1	Lightning
Midian	614	5- 1-44	1:02 a.m.	GB1	Lightning
Ripley	614	5-29-44	4:39 p.m.	GB1	Lightning
Midian	614	5-29-44	4:39 p.m.	GB1	Lightning
Ripley	614	7- 8-44	9:17 p.m.	GB1	Lightning
Midian	614	7- 8-44	9:17 p.m.	GB1	Lightning
Ripley	614	7-10-44	3:17 p.m.	GB1	Lightning
Midian	614	7-10-44	3:17 p.m.	GB1	Lightning
Ripley	614	7-11-44	4:22 a.m.	GB1	Lightning
Midian	614	7-11-44	4:22 a.m.	GB1	Lightning
Ripley	614	7-18-44	8:42 a.m.	GB1-A1	Lightning
Midian	614	7-18-44	8:42 a.m.	GB2	Lightning
Ripley	614	7-25-44	3:03 a.m.	GB1	Lightning
Midian	614	7-25-44	3:03 a.m.	GB1	Lightning
Ripley	614	7-27-44	9:43 p.m.	GB1	Lightning
Midian	614	7-27-44	9:43 p.m.	GB1	Lightning
Ripley	614	8-13-44	5:50 p.m.	GB1-A1	Crossarm broken
Midian	614	8-13-44	5:50 p.m.	GB2	Crossarm broken
Midian	614	8-13-44	5:51 p.m.	GB2	Crossarm broken
Ripley	614	8-13-44	6:21 p.m.	GB1-A1	Crossarm broken
Ripley	614	9-10-44	4:20 a.m.	GB1	Lightning
Midian	614	9-10-44	4:20 a.m.	GB1	Lightning
Ripley	614	11- 2-44	10:37 p.m.	GB1	Lightning
Midian	614	11- 2-44	10:37 p.m.	GB1	Lightning

Table II. Typical Relay Operating Record

Augusta–64th Street Line

	OCB Number	Date	Time	Relays	Cause
Augusta	612	1-27-44	12:28 a.m.	A1	Wind storm
64th Street	612	1-27-44	12:28 a.m.	A1	Wind storm
Augusta	612	4-26-44	12:37 a.m.	GC1	Lightning
64th Street	612	4-26-44	12:37 a.m.	GC1	Lightning
Augusta	612	6- 8-44	3:24 p.m.	GA1	Lightning
64th Street	612	6- 8-44	3:24 p.m.	GA1	Lightning
Augusta	612	6-18-44	7:25 p.m.	GB1	Lightning
64th Street	612	6-18-44	7:25 p.m.	GB1	Lightning shattered insulator
Augusta	612	6-18-44	7:26 p.m.	GB1	Lightning shattered insulator
Augusta	612	6-18-44	7:34 p.m.	GB1	Lightning shattered insulator
Augusta	612	7-27-44	9:53 p.m.	GC1	Lightning
64th Street	612	7-27-44	9:53 p.m.	GC1	Lightning
Augusta	612	8-24-44	7:01 a.m.	GB1	Lightning
64th Street	612	8-24-44	7:01 a.m.	GB1	Lightning

viously mentioned, they also require an auxiliary current transformer for zero-phase-sequence compensation. The experience has been that these disadvantages are not of such a nature that they should preclude the use of distance ground relays.

The relay installation for each oil circuit breaker consists of three distance phase relays and three distance ground relays, a total of six relays. It would be possible, by means of current and potential switching circuits, to reduce the number of relays required to one phase relay and one ground relay,[3,4] but with some increase in tripping time. It is believed that the scheme employing two relays has its principal application on subtransmission lines, 33 kv and lower, rather than on important 60-kv and higher voltage lines.

Relay Installations

The first installation on the Kansas Gas and Electric Company 60-kv system was completed October 6, 1938, and was followed from time to time by other installations, until at the present time ten installations of distance ground relays are in service.

A 1-line diagram of the Kansas Gas and Electric Company Central Kansas 60-kv system is shown in Figure 3. The loca-

Figure 5. Installation of distance phase and distance ground relays (the three top relays are ground relays)

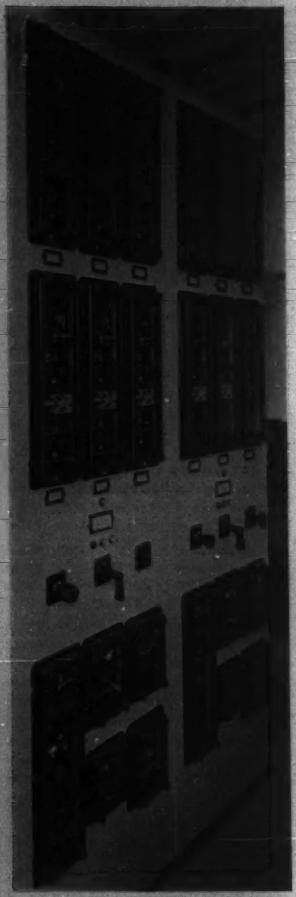

Figure 6. Installation of distance phase and distance ground relays for two 60-kv circuit breakers

The phase relays are across the top of the panel and the ground relays are across the middle. The relays in the lower section are, with the exception of the auxiliary blocking relay, associated with the ground relays for automatic reclosing and synchronous check functions

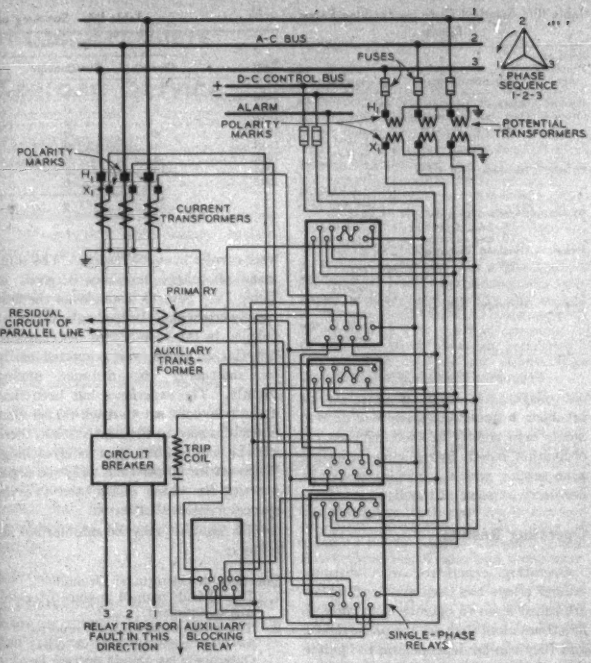

Figure 7. Typical wiring diagram for one type of distance ground relay installation

tion of distance ground relays is indicated by symbol on this diagram. The dates on which the various installations were completed are as follows:

Ripley 614	October 6, 1938
64th Street 602	April 4, 1941
64th Street 612	April 4, 1941
Augusta 612	May 9, 1941
Wichita 604	June 7, 1941
Midian 608	July 14, 1942
Midian 614	July 23, 1942
Augusta 608	August 17, 1942
Boeing 602	February 4, 1943
Boeing 604	February 4, 1943

Previous to the installation of distance relays and other modern relays on this system, induction overload and directional relays were used. Ground relays were installed on only a few of the circuit breakers. Co-ordination between the relays on the various circuit breakers was by time sequence, taking advantage of the diversity of current flow in the various circuits under fault conditions as much as possible. Instantaneous overload relays, set to cover 90 per cent of the line length under maximum generating conditions, were used on lines which were long enough to secure reasonable coverage under average generating conditions. At this stage, Boeing and 64th Street substations had not been built and the Wichita–Augusta line was one continuous line. Nor had Ripley been built, but there was a 60-kv substation not far from the plant site having three 60-kv circuit breakers, making the same system connections as the three circuit breakers at Ripley do now. Even with the help of the instantaneous relays on the longer lines, the relay time on the majority of the circuit breakers at Wichita Plant and Midian were quite long. In addition, it was found impossible to find relay settings which would fit all system conditions. Instability troubles frequently developed between Wichita and Midian because of the long relaying times involved.

Sometimes the opinion is expressed that zone type distance relays cannot be applied to a system on which they must be co-ordinated with induction overload relays. It is believed, however, that this fear has been exaggerated. No particular difficulty has been experienced in applying distance relays to the system under consideration. The distance relays were put in service, one or two installations at a time, over a period of several years, with the old induction relays continuing in service on the remaining circuit breakers. In fact the transition is still not complete since, as can be seen on Figure 3, six circuit breakers remain which have the

Table III. Standard Code for Marking Relay Targets

Kind of Protection	Function or Type	Symbol
Ground	Overload, time delay	G
Ground	Overload, instantaneous	G1
Ground	Distance; HX, GCX	GA1, GB1, GC1 (for zone 1); GA2, GB2, GC2 (for zone 2); GA3, GB3, GC3 (for zone 3)
Phase	Overload, time delay; IA, IAC, CO, CR, IB, and so forth	A, B, C
Phase	Overload, instantaneous	A1, B1, C1
Phase	Distance; HZ, GCX	A1, B1, C1 (for zone 1); A2, B2, C2 (for zone 2); A3, B3, C3 (for zone 3)

Table IV. Summary of Distance Relay Operations

Year	Ground Relays			Phase Relays		
	Correct	Questionable	Wrong	Correct	Questionable	Wrong
1938	2	0	0	0	0	0
1939	21	0	0	2	0	0
1940	9	2	1	1	0	0
1941	40	0	1	7	0	0
1942	40	0	2	21	0	0
1943	87	0	4	16	0	2
1944	108	0	3	31	0	0
1945	71	0	0	5	0	0
	378	2	11	73	0	2

old relays. On most of these circuit breakers, instantaneous overload attachments help greatly in effecting good coordination, mostly by reducing the second zone setting which otherwise would be necessary on some of the distance relays.

Operating Results

Operating experience with distance ground relays has been excellent. They are called upon to operate from three to five times more than are the phase relays, and they can be depended on to operate correctly when properly applied.

An example of the operating performance of these relays is shown in Tables I and II, which give a part of the relay operating record of the Ripley–Midian line and the 64th Street–Augusta line respectively.

For the purpose of assisting in the understanding of the relay operations indicated in Tables I and II, Table III is included, which gives a partial list of the standard method of marking and reporting relay targets used by the Kansas Gas and Electric Company.

An analysis of the distance ground relay operations from October 1938 through 1945 discloses that there have been a total of 391 operations, of which 378 were correct in every respect. During the same period, there were a total of 75 distance phase relay operations (counting only those breakers on which distance ground relays also were installed.) Of these, 73 were correct in every respect. The summary of these operations is given in Table IV. Several instances of the first zone overreaching the next substation developed in the case of two installations, but this condition was corrected easily by shortening the distance setting slightly. The experience has been that if the relays are set to reach 85 per cent of the distance to the next station, there will be no trouble from overreaching. When set for 90 per cent, as is the usual practice for phase relays, the two instances mentioned occurred.

This analysis may be summarized as follows:

Questionable Operations: Ground

1. Zone 2 fault tripped in zone 3 (or was so reported) 1
2. Two ground relay targets reported for one "tripout" (GA1 & GB1). Only one relay should operate because of blocking units 1

Total 2

Wrong Operations: Ground

1. Overreached. Tripped in zone 1 for fault beyond next substation 3
2. Bad auxiliary contact caused unnecessary "tripout" 2
3. Loss of potential (fuse blown) 6

Total 11

Wrong Operations: Phase

1. Failure to operate because of faulty contact adjustment 2

Total 2

Loss of potential was the cause of more false operations than any other one thing. It is expected that less trouble will be experienced from this cause in the future since heavier potential transformer fuses now are used, which are not likely to fail from deterioration. Instantaneous overcurrent fault detector relays can be used to prevent tripping from loss of potential. In order to keep the burden on the current transformers to a minimum, three such relays, mounted separately, should be used to supervise both the phase and ground relays rather than equip each phase and ground relay with its own fault detector.

Conclusion

There is reason to believe that distance ground relaying deserves much wider acceptance than it has received so far, since operating experience has demonstrated that distance ground relays give results which are in every way as satisfactory as those obtained with distance phase relays, the use of which is well established.

It also is believed that if more engineers would study the possibilities of distance ground relays in combination with distance phase relays and compare them with the much more expensive and complex carrier pilot relaying, they would find that distance relaying would give adequate protection in many cases where otherwise more expensive relaying would seem desirable.

References

1. Fundamental Basis for Distance Relaying, W. A. Lewis, L. S. Tippet. AIEE Transactions, volume 50, 1931, June section, pages 430–2.
2. A New Distance Ground Relay, S. L. Goldsborough, R. M. Smith. AIEE Transactions, volume 55, 1936, June section, pages 697–703; discussion, November section, pages 1255–6.
3. Control of Distance Relay Potential Connections, A. R. van C. Warrington. AIEE Transactions, volume 53, 1934, January section, pages 206–13; discussion March section, pages 465–6, and April section, page 617.
4. Distance Relay Protection for Substransmission Lines Made Economical, L. J. Audlin, A. R. van C. Warrington. AIEE Transactions, volume 62, 1943, September section, pages 574–8; discussion pages 976–9.

High Voltage Ignitron Rectifiers and Inverters for Railroad Service

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Synopsis: Single-anode pumped-type mercury-arc-rectifier tubes have been established in the 300-, 600-, and 900-volt field in the past few years, and as a result they have become the most important type of equipment for large power conversion at these voltages. The ignitron was the major development which brought about the change from multianode to single anode tubes in this low voltage field.[1] Recently sealed ignitrons have been developed for very high voltages and lower currents.[2] This paper describes high voltage pumped ignitrons which have been made available for power conversion in the 3,000- to 4,000-volt range. The major application for mercury arc rectifiers in this voltage range is for railroad service. Therefore, the requirements for railroad loading have been given special consideration in the design of the high voltage ignitron. Both rectifier and inverter characteristics were desired in one unit so that a maximum of flexibility could be obtained. The characteristics of combined rectifier and inverter operation are described. Accepted fundamental rectifier and inverter relationships are presented, and curves are included to aid in determining operating characteristics. The design and tests which led to the successful development of the high voltage pumped ignitron are discussed. Pumped ignitrons are compared with sealed ignitrons for high voltage applications so that the field of each can be better defined.

THE DEVELOPMENT of the 3,000-volt ignitron rectifier was begun after the characteristics of single anode tube and multianode mercury arc rectifiers were compared. In low voltage applications, the lower arc drop of single anode tube rectifiers results in an appreciable improvement in the efficiency and is the determining factor in the selection of the type of rectifier. In the high voltage field, the arc drop is a smaller percentage of the direct voltage, and the lower arc drop improves the efficiency only slightly. However, single anode tube rectifiers have a number of minor advantages that are important when considered together.

The maintenance of single anode tube rectifiers is simplified because they consist of a number of similar tubes. This fact also makes it possible to operate at reduced capacity with some of the tubes removed. Since large numbers of tubes are required, mass production methods can be used in the manufacture.

Ignitron rectifiers have the following advantages over continuously excited mercury arc rectifiers:

1. Cathode spot excitation independent of load.
2. Angle of retard unaffected by load current or water temperature.
3. No moving parts in excitation circuit.
4. No cathode insulation required.

Single anode tube rectifiers have the disadvantage that their excitation circuits are somewhat more complicated. However, since the excitation circuits are almost independent of the kw rating, it is found that this disadvantage is outweighed by the advantages for the higher ratings.

Ratings

Typical ratings required for rectifier units for railroad loading are 2,000 kw and 3,000 kw. These ratings were used as a basis for the design of the 3,000-volt ignitrons.

Railroad loading usually requires very heavy overload ratings. Ignitron rectifiers are especially suited for suddenly applied overloads, because they show no tendency to cause arc surges at any reasonable water temperature and because their arc-back performance is less dependent on previous loading.

The proposed AIEE heavy duty rating,[3] which is used in the testing of high voltage rectifiers for railroad service, is the following:

100 per cent rated load continuously

150 per cent current for two hours, following 100 per cent load

300 per cent current for five minutes, following 100 per cent load

With low voltage high current ignitrons, it is found that the inverter rating of a given design is lower than the rectifier rating. In high voltage rectifier operation, the required design results in improved inverter performance.

Regeneration

One of the important requirements for a railroad substation in mountainous country is regeneration. This requirement can be accomplished by mercury arc rectifiers in a number of different ways:

1. A given unit may be operated first as a rectifier when power is required and then as an inverter when regeneration is required. A reversing switch to change the polarity of the power circuit and means for rapidly changing the ignition angles must be provided. This scheme has the advantage that duplicate equipment is not required, but has the disadvantage that a time delay is necessary to change from rectification to inversion and that the reversing switch has considerable duty.
2. Two or more units may be operated on the same bus, with one permanently connected with reversed polarity and excited as an inverter and the others being operated as rectifiers. This method provides a smooth changeover between rectification and inversion, but has the disadvantage that duplicate equipment is required.
3. Where heavy overloads and heavy regenerative loads are expected, a combination of the first two methods can be used. Both units can carry the overloads, and as the load drops, one unit can be switched over to inverter operation to carry normal regenerative loads. If a heavy regenerative load is required, both units can be changed to operate as inverters. This type of operation makes possible a smooth transition between rectification and inversion.

Figure 1 gives a typical rectifier and inverter circuit illustrating the second method, which is considered to be the most important. Load and regenerative voltage characteristics are shown in Figure 4 for a system having identical transformers for rectifier and inverter units. These regulation lines give the direct voltages for various load currents and for different ignition angles α of rectifier and β of inverter. The slope of these lines is determined mainly by the transformer reactance, and the values at zero current are proportional to the cosines of the ignition angles.

Circuit Characteristics

General Theory

In normal operation the action of any type of rectifier is to allow energy flow in only one direction, because a reverse current cannot be conducted through the rectifier elements. However, the flow of

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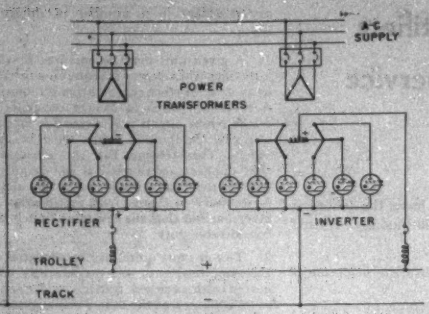


Figure 1. Delta 6-phase double-Y rectifier and inverter circuit for railroad substation

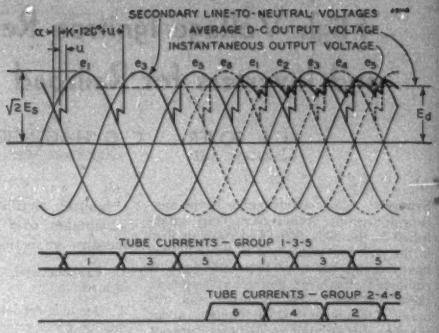

SECONDARY LINE-TO-NEUTRAL VOLTAGES
AVERAGE D-C OUTPUT VOLTAGE
INSTANTANEOUS OUTPUT VOLTAGE
TUBE CURRENTS — GROUP 1-3-5
TUBE CURRENTS — GROUP 2-4-6

Figure 2. Operation of 6-phase double-Y rectifier

energy in any circuit element can be reversed by changing either the direction of current through the element or the polarity of the voltage across the element. In a converter in which the conducting period of the elements can be controlled, the polarity of the direct voltage can be reversed by making effective the opposite polarity of the alternating voltage. This action is the principle of operation of the inverter, which permits power to be transmitted from the d-c circuit to the a-c circuit.

With railroad service, the need for regeneration is indicated by a rise in the direct voltage. The effect of this rise on rotating equipment would be to reverse the direction of current flow, but with the rectifier the elements support the additional voltage and there can be no reverse current. A second converter with a reversed connection may be controlled so that the ignitrons can conduct during periods in which the alternating voltages of their transformer windings are opposed to the flow of current. With this type of operation, energy can be transmitted from the a-c circuit to the d-c circuit by the rectifier and from the d-c circuit to the a-c circuit by the inverter.

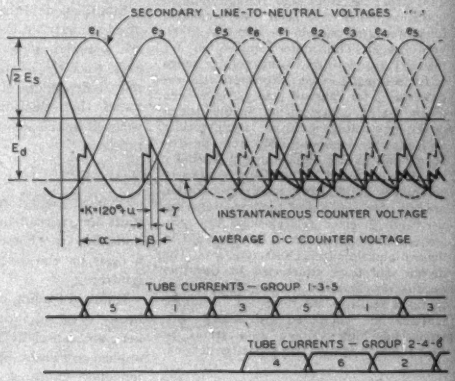

SECONDARY LINE-TO-NEUTRAL VOLTAGES
INSTANTANEOUS COUNTER VOLTAGE
AVERAGE D-C COUNTER VOLTAGE
TUBE CURRENTS — GROUP 1-3-5
TUBE CURRENTS — GROUP 2-4-6

Figure 3. Operation of 6-phase double-Y inverter

Rectifier Operation

In the simplified rectifier and inverter circuit shown in Figure 1, the rectifier operates as a normal delta 6-phase double-Y rectifier, since operation is not changed greatly by the addition of the inverter. Two separate transformers may be used as shown, or one transformer with a single primary may be used. The rectifier output voltage and current wave forms are shown in Figure 2.

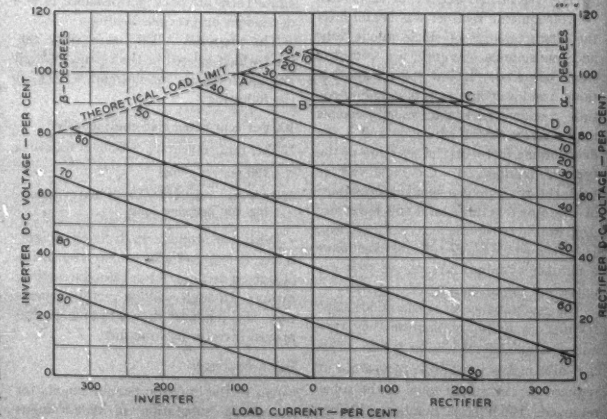


Figure 4. Regulation curves of rectifier and inverter, eight per cent regulation and same transformer secondary voltages

The average value of the d-c output voltage of a rectifier at no load with ignition delay is*

E_{dc} = theoretical average value − average arc drop

$$E_{dc} = E_{d_0} \cos \alpha - E_a \quad (1)$$

where

$$E_{d_0} = \sqrt{2} E_s \frac{p}{\pi} \sin \frac{\pi}{p}$$

The average value of the d-c output voltage of a rectifier under load is

E_d = theoretical average value − commutating reactance drop − resistance loss drop − average arc drop

$$E_d = E_{d_0} \cos \alpha - E_x - E_r - E_a$$

$$= \sqrt{2} E_s \frac{p}{\pi} \sin \frac{\pi}{p} \cos \alpha - \frac{p}{2\pi} I_c X_c - \frac{P_r}{I_d} - E_a \quad (2)$$

or, using other quantities,

$$E_d = E_{d_0} \left[\cos \alpha - \frac{\cos \alpha - \cos(\alpha + u)}{2} \right] - \frac{P_r}{I_d} - E_a \quad (3)$$

For a delta 6-phase double-Y circuit, $p = 3$ and $I_c = I_d/2$. Therefore,

$$E_d = 1.17 E_s \cos \alpha - 0.239 I_d X_c - \frac{P_r}{I_d} - E_a \quad (4)$$

For a delta 6-phase star circuit and a delta 6-phase fork circuit, $p = 6$ and $I_c = I_d$. Therefore,

$$E_d = 1.35 E_s \cos \alpha - 0.955 I_d X_c - \frac{P_r}{I_d} - E_a \quad (5)$$

Inverter Operation

Figure 3 shows the operation of a 6-phase double-Y inverter. Each anode conducts during the negative portion of the corresponding alternating voltage wave, in order to provide a d-c counter voltage opposing the flow of current.

The average value of the d-c counter voltage of an inverter at no load is

$$E'_{dc} = E'_{d_0} \cos \alpha' - E'_a$$

or

$$= -[E'_{d_0} \cos \beta' + E'_a] \quad (6)$$

where

$$E'_{d_0} = \sqrt{2} E'_s \frac{p'}{\pi} \sin \frac{\pi}{p'}$$

The average value of the d-c counter voltage of an inverter under load is

$$E'_d = E'_{d_0} \cos \alpha' - E'_x - E'_r - E'_a$$

$$= \sqrt{2}\, E'_s \frac{p'}{\pi} \sin \frac{\pi}{p'} \cos \alpha' - \frac{p'}{2\pi} I'_c X'_c - \frac{P'_r}{I'_d} - E'_a \quad (7)$$

or, using other quantities,

$$E'_d = E'_{d_0} \left[\cos \alpha' - \frac{\cos \alpha' - \cos(\alpha' + u')}{2} \right] - \frac{P'_r}{I'_c} - E'_a$$

$$= -\left\{ E'_{d_0} \left[\cos \beta' + \frac{\cos(\beta' - u') - \cos \beta'}{2} \right] + \frac{P'_r}{I'_c} + E'_a \right\} \quad (8)$$

For a delta 6-phase double-Y circuit,

$$E'_d = -\left[1.17\, E'_s \cos \beta' + 0.239\, I'_d X'_c + \frac{P'_r}{I'_d} + E'_a \right] \quad (9)$$

For a delta 6-phase star circuit and a delta 6-phase fork circuit,

$$E'_d = -\left[1.35\, E'_s \cos \beta' + 0.955 I'_d X'_c + \frac{P'_r}{I'_d} + E'_a \right] \quad (10)$$

Combined Characteristics

Under normal operating condition of a rectifier and an inverter, as shown in Figure 1, the ignition angles must be such as to have the rectifier average d-c output voltage less than or equal to the inverter average d-c counter voltage, so as to prevent circulating currents. In the 6-phase double-Y circuit, there is a light load voltage rise in the rectifier and a light load voltage dip in the inverter. These changes occur when the load current becomes less than that required for magnetizing the interphase transformer, resulting in a transition to 6-phase conduction periods. These light load voltage changes can be eliminated by adjustment of ignition angles so that a small current circulates between the rectifier and inverter when there is no load on the system.

Figure 4 shows the combined characteristics of a rectifier and inverter for various ignition angles, with eight per cent regulation neglecting losses.

The rectifier curves have dropping voltage characteristics and are to the right of the zero current axis, and the inverter curves have rising characteristics and are to the left. The inverter curves terminate at the theoretical load limit line, where the commutation angles are exactly equal to the advance angles. In actual operation it is necessary to operate below the theoretical load limit so as to provide margin angles greater than tube deionization requirements.

When the transformer secondary voltages are the same for both rectifier and inverter, it is necessary to operate at high angles of delay in the rectifier to have

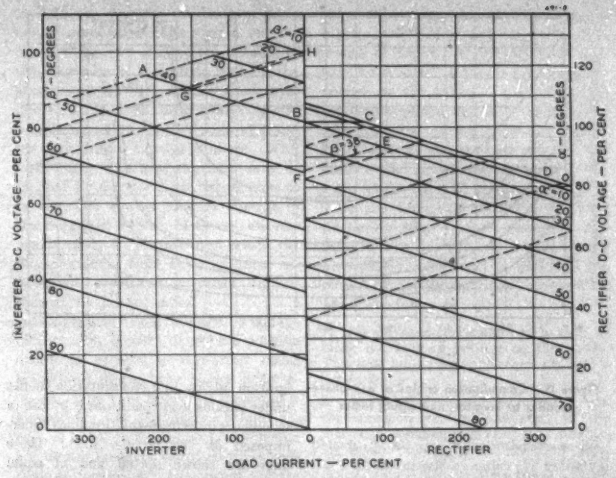


Figure 5. Regulation curves of rectifier with eight per cent regulation, and inverter with six per cent regulation and higher secondary voltage

* Definitions of the symbols are given at the end of this paper. Unprimed symbols are used for rectifier quantities and primed symbols are used for inverter quantities.

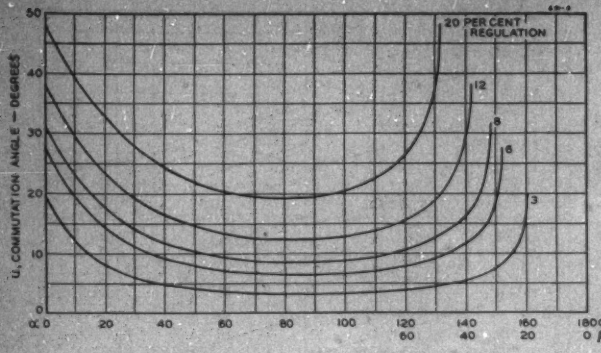


Figure 6. Commutation angles of a p-phase rectifier or inverter, neglecting losses

$$\text{Per cent regulation} = \frac{E_{do} - E_d}{E_d} 100,\ E_d \text{ at rated } I_d \text{ and } \alpha = 0$$

$$\frac{\cos\alpha - \cos(\alpha+u)}{2} = \frac{\text{regulation}}{1+\text{regulation}}$$

α = angle of retard, degrees
β = angle of advance, degrees

sufficient advance angles in the inverter to carry the required regenerative loads. For the inverter to carry 100% current, the theoretical minimum advance angle β must be 32 degrees, shown along line AB. Actually less than 100 per cent current can be carried at this angle. The rectifier must operate at a minimum of 32 degrees delay at B to avoid circulating currents. As load is increased, the voltage may be kept constant by phase control from B to C.

Figure 5 shows a condition which is more practical. The rectifier is not required to operate at high angles of delay, by having a higher transformer secondary voltage on the inverter. The direct voltage of the rectifier is held constant between B and C by phase control as the load increases. With further increase in current, the voltage will drop along the $\alpha = 0$ line from C to D.

Regenerative loads will be carried by the inverter with a d-c counter voltage given by the line AB, for $\beta = 40$ degrees. Any desired voltage characteristic can be obtained by automatically changing the firing of the inverter as the load changes, providing care is taken to operate at a sufficient amount below the theoretical load limit line.

A method of making reasonably accurate determinations of rectifier voltage, ignition angles, and commutation angles under various load conditions is by use of imaginary inverter regulation lines superimposed on the rectifier lines. These lines are shown dotted and of equal slope as the rectifier lines, but with rising characteristics. The advance angles β of these lines are equal to the delay angles α of rectifier lines starting from the same point on the zero current axis. From the symmetry of the rectifier and inverter voltage wave forms (Figures 2 and 3), the imaginary β values correspond to α plus u values of the rectifier.

The direct voltage of the rectifier at rated current and 20 degrees delay can be found by moving down on regulation line BE for $\alpha = 20$ degrees from B to 100 per cent current at E, and reading 93 per cent rated voltage opposite E. The imaginary inverter line EF gives $\beta = 38$ degrees by interpolation between the 30- and 40-degree lines. The rectifier commutation angle u is equal to 38 minus 20, or 18 degrees.

Inverter conditions can be determined in a similar manner by using the dotted imaginary rectifier lines. For example, the inverter counter voltage for 150 per cent current at 40 degrees advance is given as 90 per cent at point G. The imaginary rectifier line GH gives $\alpha = 21$ degrees as the imaginary rectifier ignition angle; this value corresponds to the inverter margin angle γ. The inverter commutation angle u then is β minus γ, or 40 minus 21 equals 19 degrees.

Choice of Circuit

Most of the 3,000-volt mercury arc rectifiers which have been applied up to the present time have used 6-phase star or fork transformer secondaries. The important reason for this use has been to avoid the light load voltage rise of the double-Y circuit. However, in stations in which there are both rectifiers and inverters, the light load rise can be eliminated as described previously. For a given rated direct current and for equal direct voltage regulation, the 6-phase double-Y circuit has the following advantages over the star or fork connections:

1. Peak anode currents are half.
2. Rms anode currents are lower by ratio of $\sqrt{2}$.

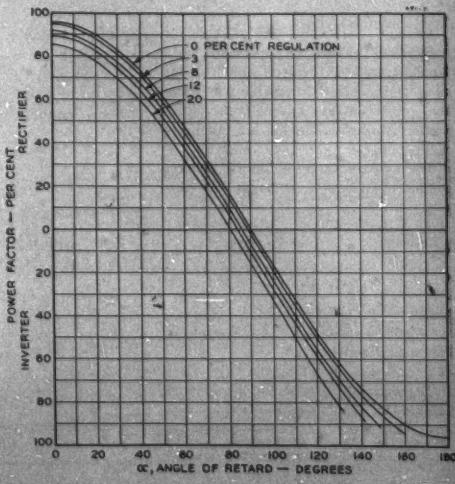


Figure 7. Power factor of 6-phase rectifier or inverter at rated current, neglecting exciting currents and losses

3. Transformer kilovolt-amperes is lower.

4. Final commutation rate of anode current is lower by the ratio of 2.

5. Short circuit and arc back currents are lower.

6. Low transformer commutating reactance is not required.

The 6-phase star or fork circuits have the following advantages:

1. Initial inverse voltage is lower by ratio of 2.

2. There is no light load voltage rise.

The circuits are the same in the following:

1. Average anode currents are equal.

2. Peak inverse voltages are equal.

3. Commutation angles are equal.

4. Power factors are equal.

Figure 6 shows the commutation angles of any type of rectifier circuit as a function of the angle of retard and the d-c regulation, neglecting losses. Figure 7 shows the theoretical power factor of the 6-phase double-Y, the star, and the fork circuits as a function of the angle of retard and voltage regulation.

Faults

The important type of electronic fault with rectifier operation is the arc-back, which is defined as the failure of the tube to hold the negative anode to cathode voltage, with the result that a current flows in the reverse direction because of the formation of a cathode spot on the anode. An arc-back on one anode produces a short circuit on both the d-c and a-c circuits and must be cleared by opening both the a-c and d-c breakers. With high voltage rectifiers, the tubes may be blocked by electronic arc suppression to prevent the flow of forward current in the unfaulted tubes. However, the d-c breaker must be opened to interrupt the flow of current from any equipment capable of sustaining a direct current through the faulted tubes.

If a rectifier is operating with voltage reduction by ignition delay, the positive anode to cathode voltage may cause breakdown of the tube before it is released. This type of fault is known as a forward-fire. If only one such fault occurs, it is self-correcting without opening any circuit breakers, but if all tubes continue to forward-fire, the output voltage will be increased and the unit may be overloaded. With ordinary water temperatures and the tight shielding used on high voltage rectifiers, faults of this type almost never occur.

Another general class of faults is the misfire, which is the failure of a tube to begin conducting at the proper time. An occasional misfire in a rectifier will not cause any serious disturbance, but a series of misfires will result in the lowering of the average output voltage.

In inverter circuits the voltages are such that an arc-back will not cause a tube to continuously carry current in the reverse direction. An inverter tube may have an arc-back caused by the negative voltage on the anode at the end of the conduction period, but the voltage on the tube reverses and stops the flow of the fault current. An arc-back usually will lead to the arc-through, which is the more serious fault of the inverter.

An arc-through is defined as the conduction of power circuit current in the forward direction through a tube during a scheduled nonconducting period of the cycle. An arc-through may be caused by one of the following:

1. Forward-fire, the failure of a tube to block the forward voltage on the anode. This tube fault may or may not produce a circuit fault.

2. Misfire, the failure of a tube to begin conducting current at the start of the scheduled conducting period, thus producing an arc-through on the preceding tube. It is a fault caused by either the excitation circuit or the tube and always produces a circuit fault for at least one cycle.

3. Recommutation, the failure of the load current to be commutated completely from one tube to another within the required angle, with the result that current is commutated back to the original tube. It is a fault caused by the power circuit.

If a rectifier and an inverter are operating on the same bus and an arc-back occurs on the rectifier, the inverter will

Figure 8. Single-grid high-voltage ignitron

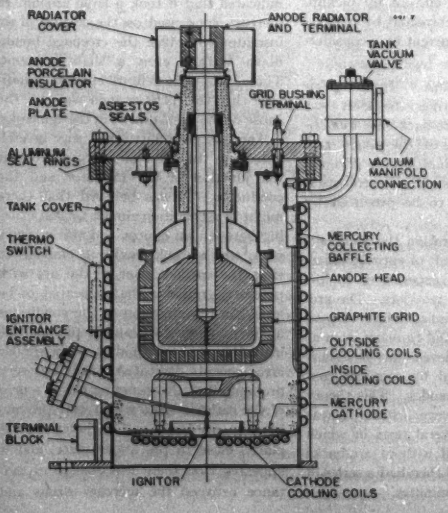
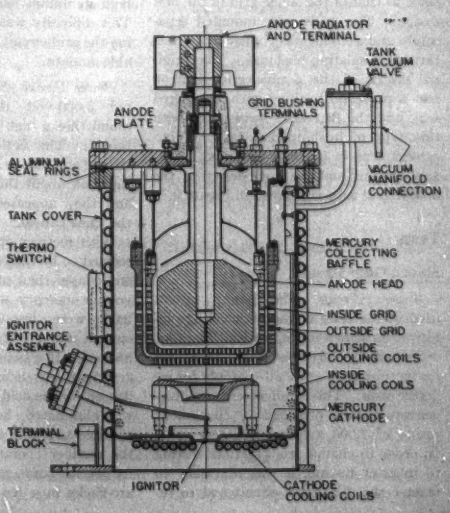


Figure 9. Double-grid high-voltage ignitron



not feed current into the short circuit. However, if an arc-through occurs on the inverter, the rectifier will supply a fault current to the inverter. The other tubes in the inverter, which do not have a fault, do not supply any current to the faulted tube or tubes. If the units are identical, the peak arc-back currents are about equal to the peak arc-through currents.

Ignitron Design

In the design of the 3,000-volt pumped ignitron, attention was given to obtaining a rectifier with a low arc-back rate and high overload capacity. The operating outlet water temperature was to be 55 degrees centigrade. The same design was to be used for either the rectifier or the inverter, and the shielding of the anode was to be such that only ignitor control would be required for either type of operation.

To accomplish the above objectives, two designs of ignitrons were made at about the same time. Both of these were manufactured and placed on test. The results were compared, and the best design was selected and given additional tests.

The first design of ignitron used a single grid with a high ion attenuation and with a high deionization influence around the anode. A porcelain anode bushing with a soldered seal was used on this design. Figure 8 shows the cross section of this single grid design.

The second design used two grids having a total deionizing effect about the same as that of the single grid in the first design. The grids were mounted separately and a circuit was connected to each through insulating bushings. The original design of the double grid ignitron had a porcelain bushing with a soldered seal, and the first tests were made with this type of bushing, but later an improved type of bushing was used. This new bushing and the final design of the double grid tube are shown in Figure 9.

Tests

Single Grid Design

Power Circuit. The power circuit used in the tests of the high voltage ignitrons is shown in Figure 10. The four d-c machines were used either as a load for rectifier tests or as a d-c supply for inverter tests. This arrangement of motor-generator sets provided a continuous rating of 2,000 amperes at 3,000 volts. In order to change from rectifier testing to inverter testing, it was necessary to reverse the d-c power circuit and to reverse the polarity of the holding coil in the high speed d-c breaker.

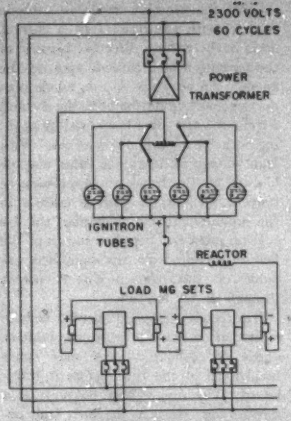


Figure 10. Circuit for laboratory tests of high voltage ignitrons

Excitation Circuits. At the start of the high voltage tests, standard firing and grid circuits were used. The grid circuit soon was found to be unsatisfactory for the 3,000-volt ignitron, as there was difficulty in the pickup of the main anode. At normal operating temperatures, the firing of the ignitors and the pickup of the grids were satisfactory, but the main anode had frequent misfires and required high minimum load current for pickup. This difficulty was corrected by increasing the grid circuit current by a considerable amount.

Power Circuit Faults. In the original 3,000-volt rectifier tests, it was found that a high arc-back rate was obtained. The faults of the single grid design and the original double grid design had about the same characteristics, and they appeared to be produced by the same causes.

With rectifier operation the arc-backs seemed to be the result of entirely different causes than are experienced in low voltage mercury arc rectifiers. The arc-backs were almost independent of load current and were found to occur even at no load. It was believed that this characteristic was caused by mercury condensed on the cold anodes. This theory was eliminated, however, when it was possible to make several tests in which the rectifier operated without arc-backs for several hours and then had a series of arc-backs in a few minutes. Operation at reduced voltage to warm the ignitrons, and then change to the high voltage did not improve the performance and indicated that mercury on the anodes was not the major cause of the arc-backs.

One of the important clues as to the cause of arc-backs was the phase angle in the inverse voltage period at which they occur.[7,8] The most accurate and complete data were obtained by the use of the memnoscope.[9] A memnoscope oscillogram of the anode to cathode voltage of three tubes is shown in Figure 11. The fault occurred near the peak inverse voltage, where the anode to cathode voltage dropped to zero. In most of the records taken of the high voltage ignitrons, the faults occurred near the peak of the inverse voltage. The breakdown characteristics of the ignitrons were investigated with no ionization in the tubes. It was found that a new tube just degassed would break down at slightly below its rated inverse voltage. However, if the testing was continued with repeated breakdowns, the voltage held between the anode and cathode could be increased to many times the rated value.

One of the first phenomenon which was investigated was the effect of mercury dew on the surface of an insulator. It was thought that enough mercury could be condensed to reduce substantially the value of the creepage distance on the insulator. A test setup was made in which a voltage stress could be placed on an insulator with a controllable temperature in mercury vapor at pressures corresponding to those in an ignitron. This test indicated that it took a large amount of mercury condensed on the surface of an insulator to reduce the creepage breakdown voltage even a slight amount. These tests were definite enough to indicate that this phenomenon was not the cause of the breakdowns in the ignitrons.

Another possibility that was investigated was the effect of mercury drops at the junction of the insulator and the conductor. It was believed that there might be a condition similar to that existing between an ignitor and the mercury pool, which would make it possible to start the cathode spot of the arc with potential gradients that appeared to be low. An investigation of the conditions at the junction of the anode stem and the insulator, and of models with similar arrangements, indicated that it was very probable that this junction was a source of the cathode spots which were producing the arc-backs. The junction was placed close to the anode plate, and it appeared that there was enough capacitance between the mercury drops and

the anode plate to produce cathode spots at the junction. Another, but less likely, explanation was that high resistance ignitor action took place at the junction, even though most of the insulator did not have mercury on it.

Since condensed mercury was the cause of the arc-backs, bushing heaters were used so that the junctions were held at a temperature at which mercury would not condense. An interesting fact was observed that at higher loads, higher bushing temperatures were required to prevent the start of a series of arc-backs. Heavy overloads frequently were found to produce arc-backs which occurred 10 or 15 minutes after the overload was completed. These arc-backs also were corrected by operating with a sufficiently high bushing temperature.

In the investigation of the probable causes of arc-backs, a high voltage ignitron was built with several windows in the tube. The conditions in the tube during the various portions of the cycle were investigated by means of a stroboscope. One observation was that large numbers of mercury drops were moving in the grid-cathode space at high speed. It was believed that if one of these mercury drops hit the hot anode during the negative portion of the cycle, there would be a high probability for an arc-back. By using a special design of grids and baffles it was possible to shield the anode from the drops. However, it is still possible that this factor may be one of the important causes of arc-backs in all mercury arc rectifiers.

Double Grid Design

Power Circuit. The power circuit used in testing the double grid design was the same as that used for the single grid design and is shown in Figure 10. For some of the rectifier tests and for most of the inverter tests, the d-c inductance was increased so that there was less ripple in the direct current.

Excitation Circuit. The use of a double grid tube greatly increased the number of types of excitation circuits which could be used. However, it was desirable to keep the excitation circuit as simple as possible. With the double grid ignitrons, there was little trouble with pickup, either of the inside grid or the anode, because the ion attenuation of each grid was not unusually high. For rectifier operation, it was found that the most desirable grid circuit was with sine wave excitation at a low voltage, and with angles of retard determined by the ignitors.

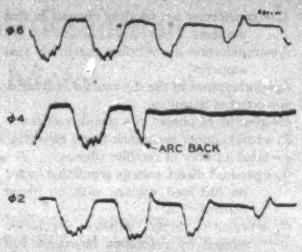


Figure 11. Oscillograms of anode-cathode voltages, showing arc-back in phase 4

For inverter operation, the problem of excitation was found to be more difficult. For inverter operation with normal overloads, the same low voltage grid circuit and ignitor control could be used as in rectifier operation. However, if unusually high overloads were required on the inverter, it was necessary to use a grid circuit in which the outer grid released the inner grid when the ignitor was fired.

Rectifier Tests. The rectifier tests with double grids and porcelain-enclosed glass kovar sealed bushings were considered very satisfactory. The new bushing was found not to be critical to the collection of mercury dew, as its permissible operating temperature was far above that at which mercury would condense in the tube. This condition made it possible to eliminate completely the bushing problem, since a high temperature could be maintained by the use of anode and bushing heaters.

The use of a double grid greatly increased the load current which could be carried with a permissible arc-back rate. By operating the grids at low voltage, forward-fires practically were eliminated, even when operating at high angles of ignition delay. The rating obtained for the rectifier was higher than the required rating.

Inverter Tests. The double grid ignitrons operated as inverters with ignitor control, making it possible to have a simple excitation circuit. The limiting rating of the inverter was less than that of the rectifier.

Most of the faults which occurred in the inverter were arc-throughs caused by forward-fires. The memnoscope oscillograms indicated that the loss of control usually occurred just after the anode became positive. Rarely, a recommutation fault was observed when there was a disturbance in the a-c line voltage caused by some other equipment on the shop bus.

Sealed Ignitron Tubes

The possibility of using sealed ignitron tubes for the 3,000-volt class should be considered for some railroad applications. Sealed ignitrons have been developed for voltages up to about 7,000 volts d-c in single way circuits, and economical designs could be obtained for 3,000 volts.

There should be no fundamental difference in the performance of pumped and sealed ignitrons. Up to the limit of size for which experience has been obtained in sealed tube construction, any electrical design used in pumped tubes also can be used in sealed tubes with an equal rating.

The decision as to whether pumped or sealed ignitrons should be used in a given application should be based on the relation between the required continuous and overload ratings and the available tube ratings. Economic considerations may be the determining factor for some current capacities.

Conclusions

High voltage pumped ignitrons of an improved design have been built and tested for the requirements of 3,000- to 4,000-volt railroad service. All of the circuit characteristics, which are available with grid controlled rectifiers and inverters, are obtained by the use of ignitor control. Rectifiers and inverters can be used in one substation to provide the desired characteristics for either load or regeneration.

The high voltage ignitrons are designed for heavy overloads of the type required for railroad service. A new design of porcelain-enclosed glass kovar sealed anode bushing, which has a temperature limit far above that obtained in normal operation, has been developed.

The selection of either pumped or sealed construction for high voltage ignitrons must be based on the rating, economic factors, and special requirements for each application.

Nomenclature: Rectifier Symbols

a_m = coefficient of sine term of Fourier expansion for the mth harmonic (crest value)

b_m = coefficient of cosine term of Fourier expansion for the mth harmonic (crest value)

c_m = coefficient of resultant of Fourier expansion for the mth harmonic (crest value)

E_a = average direct voltage drop caused by loss in the converter elements (average arc drop)

E_d = average direct voltage under load

E_{do} = average direct voltage, no load, with phase control and with arc drop

E_{dx} = theoretical direct voltage (average direct voltage at no load assuming no overlap, no phase control, and zero arc drop)

E_H = initial inverse anode to cathode voltage

E_L = a-c system line-to-line voltage in rms volts

E_N = a-c system line to neutral voltage in rms volts

E_{pf} = peak forward anode to cathode voltage

E_{pi} = peak inverse anode to cathode voltage

E_r = average direct voltage drop caused by resistance losses

E_s = transformer direct winding line to neutral voltage in rms volts

E_x = average direct voltage drop caused by commutating reactance

ΔE = total average direct voltage drop because of regulation

f = frequency of a-c power system

$F_x = \frac{I_s X_c}{E_s} = 2\sqrt{2} \sin \frac{\pi}{p} \frac{R_{pr}}{1+R_{pr}}$ = reactance factor

I = a-c line current (crest value)

I_a = average anode current

I_c = direct current commutated between two rectifying elements in a commutating group

I_d = average d-c load current

I_e = transformer exciting current in rms amperes

$I_H = \sqrt{I_3^2 + I_5^2 + I_{11}^2}$ = equivalent totalized harmonic component of I_L

I_L = a-c line current in rms amperes

I_1 = fundamental component of I_L

I_{1P} = watt component of I_1

I_{1Q} = reactive component of I_1

I_m = harmonic component of I_L, of the order m

I_p = transformer a-c winding current in rms amperes

I_s = transformer d-c winding current in rms amperes

L_d = inductance in the d-c reactor in henries

m = order of harmonic

p = number of phases in a simple rectifier

P_r = total copper resistance losses in watts

q = total number of rectifier phases

R_r = per-unit direct voltage regulation based on full load voltage with no phase control

R_{pr} = per-unit direct voltage regulation caused by reactance based on full load voltage, with no phase control and assuming no losses

R_p = ohmic resistance of the a-c winding

R_s = ohmic resistance of the d-c winding

u = commutation angle (angle of overlap)

X_c = commutating reactance line to neutral in ohms

X_L = ohms reactance of supply line (per line)

$\underline{X}_L$ = per-unit reactance of supply line (expressed on basis of rated volt-amperes at the line terminals of the transformer a-c winding)

$\underline{X}_T$ = per-unit reactance of transformer (expressed on basis of rated volt-amperes at the line terminals of the a-c windings)

α = angle of retard (delay angle, ignition angle; the angle by which the start of conduction lags the point where the incoming and outgoing rectifying elements have equal positive voltages)

$\cos \alpha$ = phase control ratio

β = angle of advance (the angle by which the start of conduction leads the point at which the incoming and outgoing rectifying elements have equal negative voltages)

γ = margin angle (the angle by which the end of commutation leads the point where the incoming and outgoing rectifying elements have equal negative voltages)

$\cos \phi$ = displacement component of power factor

$\cos \delta$ = distortion component of power factor

κ = conduction angle for one rectifying element

References

1. Ignitron Rectifiers in Industry, J. H. Cox, G. F. Jones. AIEE Transactions, volume 61, 1942, October section, pages 713–18.

2. Pentode Ignitrons for Electronic Power Converters, H. C. Steiner, J. L. Zehner, H. E. Zövers. AIEE Transactions, volume 63, 1944, October section, pages 893–7.

3. Standards for Acceptance Tests for Metal Tank Mercury Arc Rectifiers. AIEE Report 6, June 193–, sections 6–153, 6–154.

4. The Mercury Arc Rectifier Traction Substations of the Electricity Supply Commission on the Natal and Reef Electrified System of the South African Railways, K. M. Cuthff. *Transactions*, South African Institute of Electrical Engineers (Johannesburg, South Africa), March, 1941, pages 50–114.

5. A 3,000-Kw Mobile Mutator Substation for Traction Service and Regenerative Braking Duty, E. Kehl. *Brown Boveri Review* (Baden, Switzerland), May–June 1943, page 110.

6. Backfires in Mercury Arc Rectifiers, J. Slepian, R. L. Ludwig. AIEE Transactions, volume 51, 1932, March section, pages 93–104.

7. Phase Occurrence of Arc-Backs in High Current Mercury-Arc Rectifiers, W. E. Pakala, W. B. Batson. AIEE Transactions, volume 59, 1940, June section, pages 345–7.

8. The Phase of Arc-Back, A. W. Hull, F. R. Elder. *Journal of Applied Physics*, volume 13, March 1943, pages 171–8.

9. A Memory Attachment for Oscilloscopes, W. E. Pakala. AIEE Transactions, volume 57, 1938, December section, pages 682–5.

Modern Double-Reduction Traction Motor

LANIER GREER
MEMBER AIEE

Synopsis: Incorporated in the modern double-reduction motor and gear unit are many new design features which have made it an outstanding motor for the past five years. Oil lubrication is provided for all gearing and bearings in the oil-tight double-reduction gear unit. Special design constants, which have been developed as a result of many years of experience with high-speed motors, are used. Self-ventilation is successful on a high-speed motor and simplifies locomotive design. Specially insulated field coils provide for good heat transfer from the coils to steel and air. A small motor with a high-speed armature results in low copper loss and high efficiency at high tractive effort. A steep speed curve with a large amount of field shunting makes it possible to use all motors connected permanently in parallel. The motor is small, compact, and lightweight, which has made possible its use on a wide range of locomotives. Here is a small motor doing a big job.

AS EARLY as 1931, some thought was being given to the use of lightweight high-speed motors on gas-electric rail cars. The idea was to adapt motors which were designed for gas-electric drive on busses, for use in rail transportation. The first rail applications used a motor mounted either on the truck or body of the car. The motors were not designed sufficiently rugged to withstand the shock of operation when axle-mounted. On these applications automotive-type double-reduction or worm gearing was used, with a propeller shaft and double universal joints connecting the gearing and the motor. In 1938 a similar scheme was tried on lightweight industrial Diesel-electric switching locomotives. The 23-ton and 43-ton locomotives were the first on which this type of drive was used. These locomotives were equipped with a high-speed motor and double-reduction gearing.

The GE-733 is a lightweight double-reduction axle-mounted motor designed especially for Diesel-electric switching locomotives. The first of these was designed and built in 1940, and since that time a large number of these motors have been built and are in service all over the world. This machine was designed to cover a wide range of applications and therefore was built with many new electrical and mechanical features which have made it capable of doing the job well for the past five years. Figure 1 shows the motor complete with double-reduction gear unit.

More Tractive Effort

The primary objective in traction motor design is pulling power or tractive effort. It is the constant aim of the designer to secure more continuous tractive effort per pound of motor weight in each new design. If this can be done, the resulting small motor can be used on small-diameter wheels and on narrow gauge locomotives. Such a motor can be adapted to a wide range of locomotive sizes, simplifying their design. For example, weight saved in the traction motor may be used in the Diesel engine to make a more powerful locomotive without increasing the weight.

Figure 2 shows continuous tractive effort per pound of motor weight for various motors. Column *A* shows single-reduction motors which were being built in the period 1925 to 1930. Column *B* shows single-reduction motors which are being built today. Column *C* shows an early design of double-reduction motor which was built in 1936. Column *D* shows the GE-733 lightweight double-reduction motor as it now is being built and used on a wide variety of locomotives. The continuous tractive effort per pound of motor weight for the various motors shown on the chart in Figure 2 is based on the maximum reduction gearing which will give clearance under the gear case, as specified by the Interstate Commerce Commission, with the minimum wheels for which the motor is designed. This chart shows that steady progress has been made in the more efficient use of materials in both single-reduction and double-reduction motors. The continuous tractive effort per pound of the lightweight double-reduction motor is over $3^1/_2$ times as much as that of the 20-year old single-reduction motors and 43 per cent greater than that of the earlier design of double-reduction motor. This more efficient use of material is accomplished by using a high-speed lightweight motor and high torque multiplication in the double-reduction gear unit.

Figure 3 shows a graph of the continuous tractive effort and motor weight for the same groups of motors that are shown in Figure 2. For instance, the lightweight double-reduction motor weighs only one-third as much as a comparable present-day single-reduction motor and has 70 per cent as much continuous tractive effort rating. To judge a motor by this chart, place a straightedge along the abscissa and rotate it counterclockwise toward the ordinate, using zero as the center of rotation. The better motors, so far as continuous tractive effort is concerned, are nearer the ordinate.

How Much Horsepower?

A motor cannot be judged solely by its continuous tractive effort. Consideration also must be given to locomotive speed. If it were not necessary to consider locomotive speed as well as continuous tractive effort, triple-reduction or quadruple-reduction gearing could be used. This would give much higher

Figure 1. GE-733 d-c traction motor with double-reduction gear unit

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torque multiplication—and therefore a corresponding increase in tractive effort, since tractive effort is motor torque translated to the rim of the locomotive wheel. The data given in Figure 4 take into consideration locomotive speed as well as tractive effort. These factors have been combined to obtain a measure of horsepower. This has been done by the approximate formula

$$\text{Horsepower} = \frac{\text{continuous tractive effort}}{375} \times \frac{\text{maximum miles per hour}}{3}$$

The reason for the "3" in the formula is that continuous tractive effort and maximum speed never occur at the same time in a Diesel-electric locomotive. In general, the continuous tractive-effort rating comes somewhere near one-third of the maximum speed. Any motor may be used with various capacity engines, but this formula makes possible a fair comparison between motors. The chart is shown in horsepower per thousand pounds of motor weight, and is shown for both single-reduction and double-reduction motors. The nomenclature of the columns in Figure 4 is the same as that used in Figure 2. As indicated by the height of the columns, much progress has been made in the past 20 years in the design of single-reduction motors. Also, the modern double-reduction motor shows approximately 20 per cent more horsepower per thousand pounds of motor weight than the earlier double-reduction motor, and 67 per cent as much as the modern single-reduction motor. This, together with the data shown in Figures 2 and 3, indicates that there is a place for double-reduction motors in light-traction road service, as well as in industrial switching service, where maximum power and operating speeds are not too high. However, on the heavier high-speed road locomotives, the horsepower to be handled is so great that large-diameter armatures are necessary for commutation. These large diameters make it necessary to keep the revolutions per minute low on account of the centrifugal forces involved. With low revolutions per minute, there is no advantage in having double-reduction gearing, because all of the reduction needed can be built into one set of gearing.

New Double-Reduction Gear Unit

The specially designed 1-piece cast steel gear case which forms a part of the motor and gear unit is shown in Figure 5. This is a view of the axle and motor side and shows axle preparation, gear cover bolting flange, intermediate gear shaft bearing opening, bolt circle for mounting the motor, and air outlets for the motor ventilating fan. The gear cover is a separate piece and is cast of malleable iron. It is bolted to the gear case along the bolting flange. Figure 6 shows a photograph of the double-reduction gear unit with gear cover and axle caps removed. This illustration shows the gear unit completely assembled with all gearing and bearings in place. All bearings and pinions are arranged so that they can be disassembled without removing the motor and gear unit from the locomotive. Also, the complete motor can be removed and still leave the gear unit mounted in the locomotive. Thus, by using a high-speed motor, the size of the motor has been reduced to such an extent that it has become a part of the gear unit rather than the gear unit being a part of the motor, as on conventional single-reduction machines. Figure 1 shows the motor and gear unit nose support which is located so that, for either direction of motion of the locomotive, there will be no tilting to throw the gear mesh out of alignment or place a twisting load on the axle bearings under the heavy tractive efforts encountered in service. Hardened spur gearing operating in an oil-tight gear case has a long life. Both the high-speed and low-speed pinions are straddle-mounted to maintain alignment.

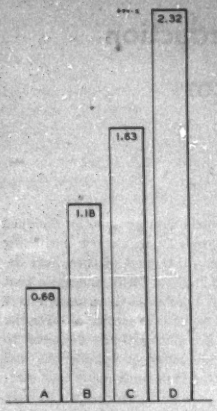
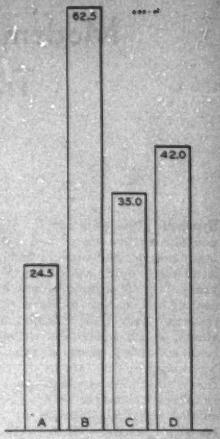


Figure 2 (left). Continuous tractive effort per pound of motor weight

Figure 4 (right). Horsepower per thousand pounds of motor weight

$$\text{Horsepower} = \frac{\text{continuous tractive effort}}{375} \times \frac{\text{max mph}}{3}$$



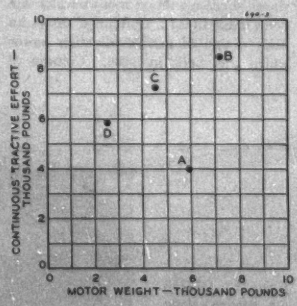


Figure 3. Continuous tractive effort and motor weight

The flood-lubricating system in the gear unit uses oil of about the viscosity of SAE 60 for normal operating temperatures, and lighter oil for lower temperatures. This lubricates all bearings in the gear unit, the pinion end motor bearing, the sleeve axle bearings, and thrust surfaces, as well as all of the gearing.

Mechanics of a High-Speed Motor

The motor is self-ventilated, which eliminates motor blowers and thus simplifies the locomotive design. This is found to be practical in a motor which is used with double-reduction gearing, since even in slow-speed switching service motor speeds are high enough to make the motor fan effective. The fan, which is mounted on the pinion end of the armature shaft, provides for multiple ventilation of the machine. One air path is over the commutator, through the space between the field coils and over the armature surface; the other is under the commutator and through longitudinal ducts in the core and armature heads.

A tight cylindrical smooth commutator is essential to the successful operation of

Figure 5 (above). Gear case for double-reduction gear unit

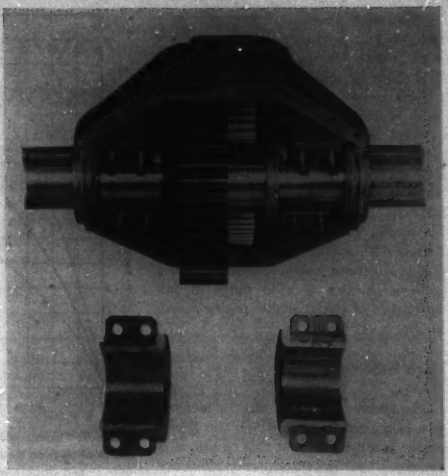


Figure 6 (right). Double-reduction gear unit with gear case and axle caps removed

any high-speed d-c machine. This is obtained by using commutator design constants, which have been developed over a period of years of experience with high-speed motors. Commutators are seasoned after the armature is completely assembled. This seasoning consists of subjecting the commutator to centrifugal forces and thermal stresses in excess of those which are encountered in service and tightening, and grinding the commutator until it operates smoothly, both hot and cold.

The armature is designed to withstand the stresses of high-speed operation that go with double-reduction gearing. The coils are held in the core slots by wedges, and the end windings are held with binding wire. The completed armature is dynamically balanced to close limits so that it operates smoothly at all speeds. It is also equipped with anti-friction bearings on both ends. The commutator end bearing housing is designed so that the armature can be removed without opening the bearing housing and exposing the bearing to dirt. This bearing also is arranged with all-metal labyrinth seals to keep grease in and to keep dirt out. The bearing on the pinion end of the motor armature is mounted outside of the motor pinion to form a straddle-mounting for the pinion. The bearing on this end is housed in the gear case and lubricated with the same oil as the gearing. The commutator end bearing is grease-lubricated.

The frame of the motor is bolted to the gear case so that the two become an integral unit and are mounted as such. Figure 1 shows a photograph of motor and gear unit.

Electrical Features

High-temperature insulating materials, such as asbestos cloth, asbestos paper, fiber-glass, and mica, are used in the modern double-reduction motor. With the aid of modern synthetic high-temperature varnishes, asbestos and mica, as well as fiber-glass and mica, have been combined to form tapes and wrappers. These materials have made it possible to use thinner insulation of a better quality and get a better-insulated machine. Thinner insulation leaves more space for copper and iron and at the same time improves the heat transfer coefficient through the insulation. Another advantage of these materials is their ability to stand high temperatures and at the same time have long life. High temperatures make it possible to get more tractive effort rating per pound of material. Inherent long life of insulating materials keeps maintenance costs low.

Proper proportioning of copper and iron in the magnetic circuit has made it possible to reduce materially the size and weight of the field structure. The field coils have been reduced in size by the use of new insulating materials and methods. Both exciting and commutating coils are edgewise wound and formed to fit the poles. They are insulated between turns with asbestos paper. A sufficient number of turns on the armature and frame sides of the coils are taped with mica and fiber-glass to provide the required insulation. Figure 7 illustrates an exciting and a commutating field coil with this type of insulation. The commutating coil is shown before the asbestos insulation has been inserted between the turns and before the coil has been dipped in high-temperature insulating varnish. The exciting field coil is shown completely insulated and ready to be mounted on the pole piece. Mica insulating collars around the pole pieces protect the field turns that are not taped. The coils are mounted on the poles and given a number of dips and bakes in high-temperature synthetic insulating varnish; thus the pole and coil become a complete unit and are assembled in the motor as such. With this type of coil, the heat transfer coefficients, both to air and iron, are much higher than for a conventional coil. After the poles and coils are assembled in the frame, the complete assembly is dipped in modern synthetic varnish and baked to fill completely and insulate all connections and joints so that they are sealed and protected from water, oil, and other foreign materials that may enter the motor.

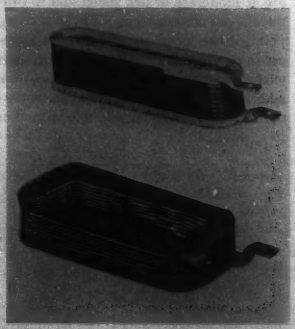


Figure 7. Exciting and commutating field coils for modern double-reduction motor

The design constants of the motor have been made to produce a steep speed curve which, with the maximum amount of field shunting, makes it possible to use the motors connected permanently in parallel. This motor connection reduces wheel slippage and gives the locomotive more pulling power. Figure 8 shows characteristic curves of the GE-733 motor on 250 volts and for two field strengths. The wide change of flux in the motor, between maximum tractive effort and maximum permissible speed, together with the engine generator characteristics, makes a locomotive with a wide range of full utilization of the available engine horsepower.

High Efficiency

The power of a Diesel-electric locomotive is limited to that which the Diesel engine can deliver. For this reason, it is necessary that the transmission efficiency be kept as high as is compatible with reasonable design. This is especially true on switching locomotives where small engines are used and where heavy loads are handled at low speeds and high tractive efforts. Figure 9 shows comparative efficiencies of various motors based on motor resistance losses at 110 degrees centigrade copper temperature, with an assumed two volts for brush drop. Curve *A* is for the older type of single-reduction motors, such as were being built in the period 1925 to 1930. Curve *B* is for single-reduction motors as they are built today. Curve *C* is for the double-reduction motor. All three of these curves are based on the maximum reduction which can be used and still maintain clearance under the gear case as specified by the Interstate Commerce Commission. A study of these curves clearly shows the advantage of the double-reduction motor for locomotives that are required to operate at moderate or low speed and to produce high tractive effort. At the starting point of the locomotive, all of the losses are in resistance. The difference between curve *B* and curve *C* in Figure 9 shows the additional tractive effort that can be produced with the modern double-reduction motor over the modern single-reduction motor for a given horsepower loss. For example, this amounts to 47 per cent increase at 30 horsepower loss.

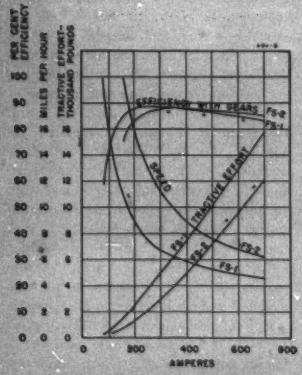


Figure 8. Characteristics of GE-733 motor on 250 volts and maximum reduction

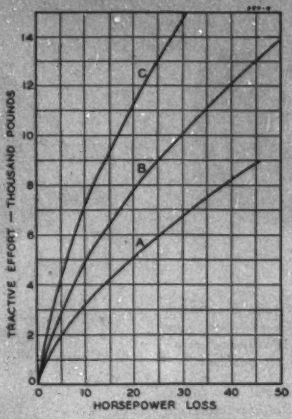


Figure 9. Comparative motor resistance loss curves of traction motors with single-reduction and double-reduction gearing

Universal Use

The modern double-reduction motor is used on a wide range of locomotive sizes. The motor has been applied on locomotives for all classes and types of industrial switching, and also for lightweight railway switching and road service.

A rule-of-thumb measure of the capabilities of the motor is given by these facts: with maximum reduction gearing, it can be applied on 50,000 pounds of locomotive weight per motor and will have a continuous tractive effort rating of 11.7 per cent adhesion, with a maximum permissible speed of 20 miles per hour.

Table I lists the locomotives on which the GE-733 motor is used. This tabulation also shows the number of motors used per locomotive, the maximum permissible speed, and the continuous adhesion rating of the locomotive. The largest number of these motors have been used on the 25-ton and 45-ton locomotives for industrial service and the 44-ton locomotive for railway service. A limited number of motors have been used on the 65-ton industrial and the 70-ton railway locomotives. In all of these applications, the double-reduction motors have given excellent service.

Table I. Tabulation of Locomotives Equipped With Modern Double-Reduction Traction Motors

Weight, Tons	No. of Motors	Max. Speed	Adhesion Per Cent
Industrial Diesel-electric locomotives			
25	1	20	11.7
45	2	20	11.7
65	4	20	11.5
Railway Diesel-electric locomotives			
44	4	35	14.6
70	4	25	13.5

Determination of Cable Temperatures by Means of Reduced-Scale Models

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Synopsis: A method, using reduced-scale model installations, is developed for the laboratory determination of cable temperatures obtaining in the field. The theory of the method is given, followed by the description of three sets of experiments conducted to show the feasibility of the method. One set of experiments is concerned with a single-conductor cable buried directly in the soil of the model setup, and temperatures obtained are compared with computed values. Another set is concerned with a single-conductor cable in a model duct bank, and sheath and duct temperatures obtained are compared with those of field determinations in an actual field installation. The third set is concerned with a model three-conductor cable in a duct bank, and conductor-sheath temperature differentials are compared with field data. All tests show that the accuracy of the method is sufficient for practical purposes.

THE determination of cable temperatures, under both stationary and transient conditions, is essential for the evaluation of maximum permissible loads. This statement follows from a consideration of the factors that limit the loads, that is, deterioration of the paper-oil insulation and undue stretching and longitudinal movement of the sheath. All these factors are considerably dependent on temperature, so that, indeed, temperature limits the loads.

Determinations of cable (conductor and sheath) temperatures can be and sometimes are carried out in the field. If, however, a wide variety of cable combinations and loading schedules is to be investigated, field tests are time consuming and costly.

A second possibility of obtaining cable temperatures is by calculation. This method, however, is suitable only for very simple arrangements, such as a cable buried directly in the ground. For duct systems of cables, a computation on a rigorous basis cannot be carried out.

A third method of attacking the problem is the use of electrical analogies. This method has been developed by Victor Paschkis[1] and applied successfully to a number of thermal problems. For several cables in duct banks, the necessary electrical equipment would be too involved, so that at present this method cannot be used for this purpose.

The method to be described in this paper was developed for the purpose of providing a more satisfactory means than those just described. As will be seen from the following, the equipment even for involved cable problems is relatively simple and, once the installation is assembled, the time required to solve any specific cable temperature problem is relatively short.

Theory

Thermal problems in a system of cables belong, strictly speaking, to the group of 3-dimensional problems, but, if the length of the cable is at least 10 to 20 times larger than the depth of the cable below ground level (a condition that is nearly always fulfilled), the heat flow along the length can be neglected as compared with the heat flow in radial directions. Thus, cable heat-flow problems can be considered as 2-dimensional.

By examining the equations of heat flow in 2-dimensional cases,[2,3] a dimensional analysis shows that there is a possibility of a scale reduction in such problems, and that the rules according to which this reduction is to be carried out are rather simple. Thus, installations can be reduced in size and yet give the same information concerning temperature distribution as the original large installations. This, briefly, is the principle of the method developed and described in this paper.

The following is a brief presentation of the dimensional analysis mentioned. One of the basic equations[2] in 2-dimensional heat problems is the temperature distribution around an instantaneous cylindrical heat source in an infinite medium, the temperature of which becomes zero at infinity. Let H_o denote the instantaneously generated heat per unit length of the cylinder with radius a, g the thermal resistivity, D the thermal diffusivity of the medium surrounding the source, T the temperature, t the time, and r the radial distance from the axis of the cylinder. Then

$$T=\frac{H_o g}{4\pi t}\exp\left[\frac{-(r^2+a^2)}{4Dt}\right]J_o\left(\frac{ira}{2Dt}\right) \qquad (1)$$

where J_o = Bessel function of the first kind and zero order. In this equation, the several variables occur in two combinations. One is (with l = any characteristic length of the installation)

$$x=\frac{p}{Dt} \qquad (2)$$

the other

$$y=\frac{T}{Hg} \qquad (3)$$

where H stands for the heat rate H_o/l and

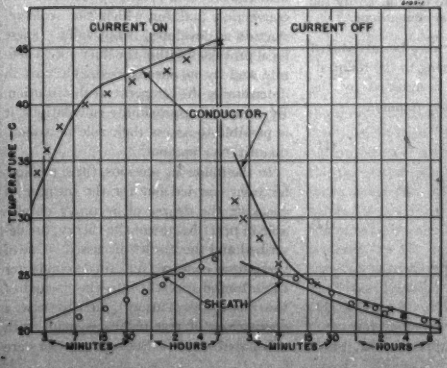

Figure 1. Temperatures of conductor and sheath of one single-conductor cable buried directly in ground of model installations

Eight-hour loading at 120 amperes and subsequent cooling (x and o are measured data; solid curves are calculated)

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has the meaning of heat generated per unit length per unit time. Both x and y are dimensionless, as is shown by the following.

D stands for l/gpc, with ρ = density and c = specific heat, and has the dimension l^2t^{-1}. Hence, x is dimensionless. Concerning equation 3, T as temperature is dimensionless, the dimension of H (heat per unit length per unit time) is mlt^{-3} (m = dimension of mass), and that of g is $m^{-1}l^{-1}t^3$; consequently, y is dimensionless. As can be seen from equations 2 and 3, equation 1 has the form

$$y = f(x) \tag{4}$$

where f stands for a function of the single argument x, containing no other parameter.

By further examining equations of 2-dimensional heat flow, it will be found that all of them can be reduced to a dimensionless form similar to equation 4. As a further example, a cylindrical space bounded by an inner cylinder of radius a, and an outer cylinder of a radius a' is considered. The inner cylinder generates heat in the amount of H per unit time per unit length; the outer cylinder is maintained at zero temperature. The thermal constants of the medium between the two cylinders are g and D, as before. The temperature of the inner cylinder T at any time t is then given[2] by

$$T = \frac{Hg}{4\pi} \sum_{n=1}^{\infty} k \left[J_0\left(\frac{\rho a}{a'}\right) \right]^2 \left[1 - \exp\left(-\frac{\rho^2 Dt}{(a')^2} \right) \right] \tag{5}$$

where

$$k = \frac{2}{\dfrac{\pi}{4+\pi-1}} \tag{6}$$

and, approximately,

$$\rho = 2.40 + (n-1)\pi \tag{7}$$

the infinite series to be extended from $n = 1$ to infinity.

It can be seen that equation 5 contains all variables in the form of x and y, as before, and, in addition, z; where

$$z = \frac{l}{l'} \tag{8}$$

l and l' denoting two characteristic lengths of the installation. Hence, equation 5 can be written in the general form

$$y = f(x, z) \tag{9}$$

f standing for a function of the arguments x and z only.

From the existence of functional equations such as 4 and 9, the conclusion is drawn that any two installations for which x, y, and z are respectively the same are physically similar. A closer investigation of equations 2, 3, and 8 reveals the conditions of similarity, as follows:

1. Equation 8 shows that a scale reduction of an installation is feasible if all linear dimensions normal to the running direction of a cable or a duct system of cables are reduced in the same ratio. For instance, the ratio a/a' in a concentrical cylindrical case should be the same both in a scale model and an actual cable.

2. If the heat-conducting substances are the same in the two corresponding installations, that is, if D is the same for both, then equation 2 shows that the time t required to attain the same temperature in both cases is reduced by a factor that is equal to the square of the reduction factor of linear dimensions. This can be seen by writing $t = l^2/Dx$ and recalling that x is the same in the original and the model. This indicates the considerable gain in time that may be obtained by carrying out temperature measurements on a reduced-scale installation. It should be added that, while the method covers transient conditions, as shown, it is obviously applicable for the limiting case of $t = \infty$, the steady-state condition. Equation 5, for instance, is valid for the steady-state condition if the exponential is replaced by zero, thus making the second bracket unity. Steady-state conditions are approached, according to equation 2, faster in the reduced-scale installation than in the original.

3. Equation 3 shows the following condition. Since the same materials are used for both the actual installation and the model, g is the same. If, now, the reduced-scale system should yield the same temperatures T as does the original system, the condition that follows from equation 3 is that H, the heat dissipated per unit time and unit length, should be the same in both cases. Disregarding dielectric and sheath losses in obtaining a first approximation, H is given by

$$H = I^2R \tag{10}$$

where I = current in a conductor and R = resistance of the conductor per unit length. Because of condition 1, the cross-sectional area is reduced by the square of the linear reduction factor, and R increases in the same ratio. Thus, in order that H be the same, the current has to be reduced by the same factor as the linear dimensions.

If the reduction factor q be introduced and if quantities referring to the reduced-scale installation be designated by the index r, then condition 1 requires

$$l_r = \frac{l}{q} \tag{11}$$

condition 2 requires

$$t_r = \frac{t}{q^2} \tag{12}$$

and condition 3 requires

$$I_r = \frac{I}{q} \tag{13}$$

The last equation is approximate; since the influence of skin effect varies with the size of conductors, a small correction factor that is available from tables has to be considered. If these three conditions are fulfilled, corresponding temperatures in the model and original installations are the same.

The larger q, the smaller is the model installation. Practical considerations, however, limit its value, and for 3-conductor 24-kv cables, a value in the approximate range of from four to five has been found to be suitable.

Test Results

The theory of scale reduction, as outlined above, does not need experimental proof, as it is based on straightforward mathematics. To what extent it could be put to use could, however, be determined only by experiment, because in building the model installation, some approximation of the theoretical requirements could not be avoided. To mention a few examples: the insulation of the model cable could not be easily built of paper five times thinner than real cable paper, that is, 1 to 0.6 mil thick; the concrete in the duct bank could not be easily built of pebbles reduced five times the original size; and the soil surrounding the duct bank could not easily be maintained at exactly the same moisture content, and hence at the same insulation level, as the soil in the field.

Apart from these approximations, resulting from a compromise because of details of construction, there is another divergence between actual installations and the conditions required by the theory as developed. The latter refers to heat transfer by conduction. This condition generally is fulfilled in cable systems with the exception of the space between the cables and the ducts, in which part of the heat transfer takes place by radiation and convection and for which the scale reduction as developed is not valid. These local processes within the duct play a definite and by no means negligible part in determining the temperature distribution. By means of approximate calculations, it is possible to assess their role in a semi-quantitative manner.

In the following sections, three particular tests, carried out for the purpose of checking the degree of accuracy obtainable in practical use of the theory, are described and the results discussed. One of these tests concerns one single conductor cable buried directly into the ground of the model installation. In this case a comparison of test results is made with calculated results. Such calculations are

feasible in this simple case. The second test refers to a single-conductor cable in a model duct system, and comparison is made with the results of an actual field test in a corresponding installation. The third test refers to a model 3-conductor cable in a model duct system and comparison is made with results of the same full scale field test as in the second test.

All these tests were carried out in a wooden box 15 feet long, 5 feet wide, and 4 feet high filled with soil (a yellow clay obtained from the location of the field installation just referred to). A volume of soil equal to that of the space in the box to be filled was dug in the field and placed in the box by tamping. Only about five cubic feet were left over, so the density of the soil in the box had nearly the original value obtaining in the ground. Moisture

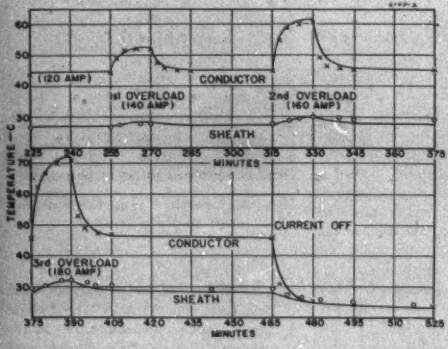

Figure 2. Temperatures of conductor and sheath of one single-conductor cable buried directly in ground of model installation

Overloads of 20, 40, and 60 amperes superimposed upon steady current of 120 amperes (x and o are measured data; solid curves are calculated)

determinations revealed that the soil contained originally 17.5 to 20 per cent water. Although a certain decrease of the moisture content with time could not be prevented, lining the box with tar paper, covering it with tarpaulin, and occasional watering of the top kept the drying out of the soil within reasonable limits. For future tests, it is considered advisable to install the model in a room in which the moisture content is artificially maintained at a relatively high level, say 80 per cent.

The thermal resistivity of the soil was measured by means of a cylindrical soil-resistivity cell[4] in the field, and shortly before removal of the sample a value of 72 thermal ohms was obtained. The diffusivity D was obtained as follows. The density ρ was 2.1 grams per cubic centimeter. The clay-to-water ratio was four to one and, since the thermal capacities of clay and water are 0.22 and 1.0 respectively, the thermal capacity of the soil is 0.37. From $D=1/g\rho c$, a value of 4.2×10^{-3} square centimeters per second was obtained for the diffusivity. These values for g and D were used in the calculations.

Single Cable Buried in Ground

This arrangement was selected because the temperature distribution in and around one single conductor cable buried in the ground could be computed theoretically. A comparison between experimental and computed data would indicate the accuracy and reliability of measurements obtained from a small size model installation.

The test cable used was a single-conductor, number 6 American Wire Gauge, paper-insulated cable having an insulation thickness of 9/64 inch, lead sheath thickness of 6/64 inch, and over-all diameter of 0.65 inch. The cable was installed ten inches below the ground surface in the box. The ratio of depth of burial to length of cable being 1 to 18, the error introduced by the end-effect, according to data of S. Whitehead,[4] was between one and two per cent.

The temperatures of both the conductor and the sheath were measured. The model method permits the copper temperature to be obtained by means of a thermocouple inside the conductor, since it is possible to pull a thermocouple into a narrow channel within the conductor. In this particular case, the central one of the seven conductor strands was pulled out before the test in order to accommodate a thermocouple; another thermocouple was soldered on the lead sheath to obtain sheath temperatures. The temperatures were continuously registered by means of a recording instrument. Thus, it is possible to maintain uninterrupted registration of copper temperatures during the whole load cycle. In contrast to this procedure, copper temperatures in field tests are obtainable only by resistance measurements, necessitating a temporary interruption of the loading.

A current transformer with the necessary control and measuring equipment was provided for the loading of the cable.

With regard to calculation of temperature in this case, equations recommended by S. Whitehead[4] were used. By considering the sheath as the source of heat flow, the basic equation 1 immediately gives the solution in the case of the buried cable. Since the ground surface is an isothermal plane, the field of an image sink above ground, added to the field of the real source, constitutes the solution of the problem. For values of $a^2/4Dt$ that are small as compared to unity, the solution for the sheath temperature T_s becomes

$$T_s=\frac{Hg_s}{4\pi}\left[-Ei\left(-\frac{a^2}{2Dt}\right)+Ei\left(-\frac{b^2}{Dt}\right)+\exp\left(-\frac{a^2}{2Dt}\right)\log 2\right] \quad (14)$$

where g_s is the thermal resistivity of the soil, Ei stands for the exponential integral,[5] and b denotes the depth of the cable below ground, the other symbols being the same as in equation 1.

The rise of the copper temperature above sheath temperature can be computed by considering both the thermal capacity C_c and the thermal resistance G_c of the cable per unit length as lumped elements, in which case the solution is an exponential. This solution, although approximate, is sufficiently accurate for the purpose at hand. The copper temperature is then given[4] by

$$T_c=HG_c\left[1-\exp\left(-\frac{2t}{C_cG_c}\right)\right]+T_s \quad (15)$$

T_s being known from equation 14. The factor 2 in the bracket is approximate: it accounts for the fact that the center of the cable is heated instantaneously, while the periphery is heated across the resistance G_c; in the average, a resistance of $G_c/2$ is operative.

The numerical values used for the two constants G_c and C_c were evaluated from the geometry of the cable and the known characteristic data of each cable constituent. G_c is given by

$$G_c=\frac{g_c}{2\pi}\log\frac{r_s}{r_c} \quad (16)$$

with g_c = thermal resistivity of insulation, r_s = inside radius of sheath, and r_c = radius of conductor. For g_c a value of 550 thermal ohms was taken. With $r_s=0.232$ inch and $r_c=0.092$ inch, the value

obtained for G_e is 81 ohms or 81×10^{-2} centimeter-gram-second units.

The thermal capacity was computed by adding the values for copper, insulation, and lead. The specific heats are respectively: 0.42×10^{7}, 1.8×10^{7}, and 0.147×10^{7} centimeter-gram-second units, resulting in thermal capacities per unit length of 0.42×10^{7}, 1.98×10^{7}, and 1.78×10^{7} centimeter-gram-second units, giving a total for $C_e=4.18\times10^{7}$ centimeter-gram-second units.

The steady-state temperatures are given by the well-known formulas:

$$T_s=\frac{Hg_2}{2\pi}\log\frac{2b}{a} \qquad (17)$$

and

$$T_c=HG_e+T_s \qquad (18)$$

Since the temperature of the conductor and, consequently, its resistance varies during a load cycle, in order to maintain a constant heat loss H, upon which the theoretical equations used for calculation are based, the current must be adjusted occasionally. This adjustment is possible when the copper temperature is registered continuously. The currents reported in the subsequent parts of this paper are the values applied at 20 degrees centigrade copper temperature and at which the conductor resistance was 15.4×10^{-4} ohms per centimeter.

The first test was carried out with a load of 120 amperes corresponding to $H=6.8$ watts per foot. Loading continued for about eight hours, after which the current was switched off. Both the heating and the cooling curves—temperature versus time—are shown on Figure 1 for the conductor as well as for the sheath. The time is plotted on a logarithmic scale. The crosses and circles indicate measured data; the solid lines were computed from equations 14 and 15, using the numerical values given.

The agreement between calculated and measured data is satisfactory, the discrepancies being generally one to two degrees centigrade, except the copper temperature within five minutes after switching off the current, where the divergence is up to four degrees centigrade. The amount of disagreement between computation and test is partly caused by the fact that the equations, although theoretical and without arbitrary constants, contain, as explained above, some unavoidable approximations. Part of the disagreement, however, is certainly caused by deficiencies of the equipment (end-effect, boundary layer between sheath and soil, drying of the soil, time lag in temperature recorder, and so forth). But

Figure 3. Details of assembly of model ducts in model trench

since a disagreement of less than two degrees centigrade is of no great practical significance, and since the cooling period is of relatively little interest to the practical cable engineer, who is not greatly concerned with the precise rate of temperature decrease after the temperature has reached its maximum, the method is considered satisfactory. For higher accuracy some of these deficiencies might be eliminated: for instance, the use, instead of moist soil, of a suitable dry and stable powdered material having the same thermal resistivity is being considered.

A second test (Figure 2) shows the temperature changes during and after short overloads. A current of 120 amperes was first maintained for about four hours (255 minutes), after which three overload cycles of 60 minutes duration, with overloads on for 15 minutes each, were applied. The total overload currents were respectively 140, 160, and 180 amperes (values reduced for 20 degrees centigrade copper temperature). The corresponding heats dissipated are 9.2, 12.0, and 15.2 watts per foot. The degree of agreement between test results and calculation is the same (deviation generally within two degrees centigrade) as in the first test. The agreement during the temperature maxima, which are of particular interest from a practical standpoint, is rather good. These findings are encouraging with regard to the practical application of a model installation (see conclusions at end of paper).

Single Conductor Cable in Duct Bank

This test was carried out in order to show whether the model was satisfactory in a case involving ducts. Since computation for such a case is not possible, a set of field tests conducted by The Detroit Edison Company was duplicated in the model setup to determine the degree of agreement between the two.

Figure 4. Completed model duct bank prior to pouring of concrete

It is planned for all tests of this type in the future to use reduced scale replicas of those cables that are involved in the actual field installations in question. At the time of carrying out the test to be described in this section, such model cable was not available, and the same single conductor cable that was used in the preceding test was installed in the model duct bank. In spite of this difference, sheath and duct temperatures, apart from the initial transients, in the model and the field should be the same. Because of the difference in the cable structures, however, copper temperatures in the field and in the model were not comparable in this particular test, and, as they are not essential in answering the specific question concerning the role of ducts in scale-model tests, they are not given here.

A fiber-conduit–concrete duct bank for 12 4-inch ducts (3 wide by 4 high; $22^1/_2$ by $28^1/_2$ inches) was reproduced in a reduced size model. The linear reduction

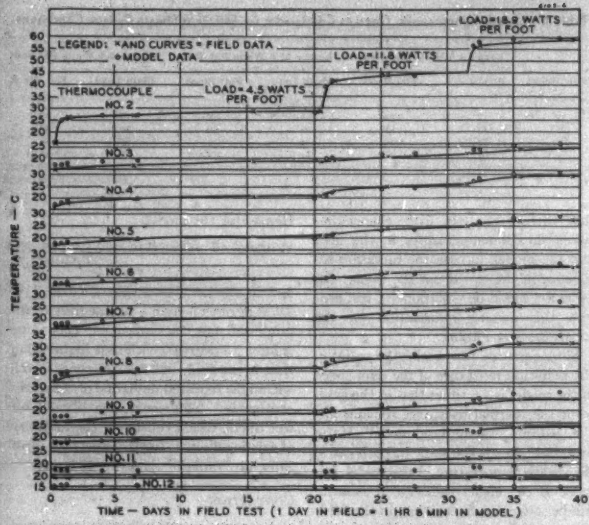

Figure 6. Temperatures of a test cable, ducts, and ground at three different indicated loads for both field and model installations

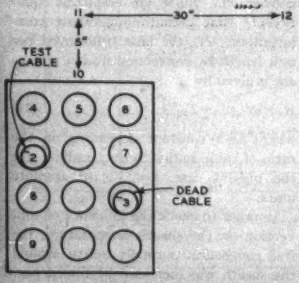

Figure 5. Diagram (not to scale) of model duct with number and location of thermocouples

factor q (see equation 11) was chosen as 4.6. This figure was selected in order to enable number 8 American Wire Gauge stranded wire to be incorporated in the model 24-kv 350-Mcm round conductor cable in the subsequent tests. The conductor diameter of the 24-kv cable is 0.68 inch, that of the number 8 wire 0.147 inch, the ratio of the two being 4.6. With q = 4.6, the inside diameter of the model ducts was 7/8 inch, and the wall thickness was 1/16 inch. Three-foot lengths of bakelite-impregnated linen tubing, joined by short pieces of 1-inch inside diameter tubing as sleeves, were used as the conduit. The thermal resistivity of this material is comparable with that of fiber conduit as used in the field. Scale model concrete spacers between the ducts were used. A scale-model trench with a cross-sectional area of 4.9×6.2 inches was dug in the soil contained in the wooden box mentioned previously, and the duct bank was assembled in the trench. The manner in which the ducts were assembled is shown in Figure 3.

Two bakelite plates attached to the end walls of the box fixed the position of the ends of the duct bank. Pebble-free concrete containing sieved sand mixed with fly ash and having a two to one sand-to-cement ratio, was poured into the trench. The soil was tamped down on top of the duct bank, the top of the concrete being $11\frac{1}{2}$ inches below the top of the soil (corresponding to four feet four inches below ground level in the field). The completed assembly, prior to pouring the concrete and refilling the soil, is shown in Figure 4.

The ends of the bank were protected from air currents by close-fitting wooden boxes attached to the outside of the main box.

The arrangement of the cables and the location and number of thermocouples, as used in the field test and in the model, are shown in Figure 5. The length of the test cables was 17 feet. It should be noted that curve 2 (thermocouple 2) refers to the sheath of the test cable (thermocouple 1, as used in the field test was not reproduced in the model); curves 3 to 9 inclusive refer to the air temperature in the center of the various ducts; and curves 10 to 12 inclusive refer to the soil.

The results of the test are shown in Figure 6. The crosses and the curves drawn through them show the temperatures, in degrees centigrade, indicated by the 11 thermocouples used in the field tests; the circles show the data obtained with the model. The 40-day field test took 45 hours in the model setup (the time reduction factor from equation 12 is $4.6^2 = 21.2$).

Since it was realized that the ducts in this particular test were wet, some water was introduced in the duct containing the test cable in the model. A total of 200 cubic centimeters was introduced in order to insure a conducting path between cable and duct wall. This point is discussed in detail later.

Three different consecutive loads were applied. According to the requirements of the model theory, the heat input per unit length of cable has to be the same in the model as in the field. The three loads applied were 4.5, 11.8, and 18.9 watts per foot, respectively.

In studying Figure 6, it can be seen from curve 12 that no attempt was made to duplicate in the model setup the ambient temperatures recorded in the field; hence, the same disagreement prevails also for curve 11. The agreement for the sheath, the various ducts, and the soil just outside of the bank (shown by curve 10) is reasonably good, with a deviation of no more than about three degrees centigrade.

Additional Tests on Single-Conductor Cable in Duct Bank

While the results shown in Figure 6 answer the chief question, namely, whether the model method works in the case of ducts, it was deemed advisable to supplement the results by a few additional tests. As mentioned previously, one of the main causes of doubt with regard to the feasibility of the model test in the case of ducts is that heat is transferred not only by conduction, but also partly by radiation and convection. The scale reduction theory, however, took into consideration conduction only. If, now, the two other mechanisms play only a minor role in ducts, the error in the model test is relatively small. While the satisfactory answer of the main test (Figure 6) answers this question in a favorable sense, it was thought advisable to strengthen the confidence in the model method by additional tests directed toward showing spe-

cifically whether the errors introduced by radiation and convection in a duct are appreciable or not.

Radiation

It is useful in this connection to consider the Christiansen equation, which controls radiation from a convex body in an enclosure[8] and which, applied to the present problem, reads approximately:

$$H_r = 2\pi a\sigma \frac{(T_s^4 - T_d^4)}{\left(\frac{1}{\epsilon_s} + \frac{1}{\epsilon_d} - 1\right)} \qquad (19)$$

where H_r = heat radiated per second, σ = Stefan-Boltzmann constant $= 5.7 \times 10^{-5}$ absolute units, a = radius of sheath, T_s and T_d = sheath and duct temperatures, in absolute units, and ϵ_s and ϵ_d = emissivities of sheath and duct. The emissivities of a tarnished lead surface and a fiber surface are 0.56 and 0.93, respectively.

In order to assess experimentally the role of radiation in the model setup, the following procedure was adopted. From equation 19 it can be seen that ϵ_s has a marked influence on the radiation. Thus by varying the emissivity of the cable surface, all other conditions being left unchanged, it is possible to determine the magnitude of the role of the radiation in a duct. The variation of ϵ_s was carried out by coating the cable with flat black, thus producing a surface with an emissivity of 0.97. The factor

$$\frac{1}{\frac{1}{\epsilon_s} + \frac{1}{\epsilon_d} - 1}$$

is then changed from 0.54 to 0.90, that is, increased by 66 per cent.

The test described in the preceding section, "Single Conductor Cable in Duct Bank," was repeated with the black sheath, and in this manner sheath temperatures, for the same watts input, were obtained with the cable coated black as were obtained with the cable in its original condition. Results, obtained at identical loads and times for the two surface conditions, are shown in Table I. The duct was dry in these tests; hence the temperatures are higher than shown in Figure 6. It can be seen that, considering the differences in the respective starting temperatures, the increases in temperature are practically identical for the two different surfaces.

The results show that a substantial change in the radiation does not cause a measurable change of the sheath temperatures in the model setup. This conclusion, while reassuring from our particular standpoint, does not, however, prove

Table I. Sheath Temperatures, Degrees Centigrade, for Different Sheath Surface Conditions

	Load = 4.5 Watts Per Foot		Load = 11.8 Watts Per Foot		Load = 18.9 Watts Per Foot	
Time, Hours	Plain Lead	Flat Black	Plain Lead	Flat Black	Plain Lead	Flat Black
0	17	20	35	37	63	62
1	33	35	59	60	84	82
2	33.5	36	60.5	61	86	85
3	34	37	60.5	62	87	85.5

that there is equally little change between sheath temperatures in the field and the model, in case the radiation resistance in the two is not the same. An estimate, based on equation 19, will provide this missing information for the steady-state condition.

Since equation 19 contains the radius a, the radiation resistance of the duct space in the model is 4.6 times that in the field, while the thermal resistance remains unchanged in a scale-reduced model. If the total heat flow is the same in both cases, the sheath temperature in the model, because of the higher radiation resistance, will be somewhat higher than in the field. It can be shown, however, that a very little increase, of the order of one to two degrees centigrade, is sufficient to satisfy the equations of heat flow in the two cases.

All data in equation 19, with the exception of T_d, are known. The latter was determined, at least approximately, by introducing a thermocouple into the duct containing the test cable and taking duct air temperatures. For a load of 11.8 watts per foot, $T_d = 35$ degrees centigrade (or 308 degrees Kelvin) was obtained, and it is probably correct to say that the same (or nearly the same) duct temperature exists in the field, too. With a cable diameter of three inches and $T_s = 43$ degrees centigrade = 316 degrees Kelvin, equation 19 yields for H_r in the field 2.2 watts per foot, which is about 20 per cent of the total heat. Neglecting convection (see the following), the balance of heat, namely 9.6 watts per foot is transferred by conduction.

The general equation for equilibrium conditions of temperature and heat flow in the duct is

$$H = A(T_s - T_d) + B(T_s^4 - T_d^4) \qquad (20)$$

where A and B are the conductances caused by heat conduction and radiation (the latter given by equation 19), and in the present case (for the field):

$$11.8 = 1.2(T_s - 308) + 2.2 \times 10^{-9} \times (T_s^4 - 9 \times 10^9)$$

and this equation is satisfied with $T_s = 316$ degrees Kelvin = 43 degrees centigrade. In the model, A remains the same, but B is reduced by a factor of 1/4.6. Hence, for the model:

$$11.8 = 1.2(T_s - 308) + 0.48 \times 10^{-9} \times (T_s^4 - 9 \times 10^9)$$

and it can be shown that a value $T_s = 317.3$ degrees Kelvin = 44.3 degrees centigrade satisfies this equation. This value is only 1.3 degrees centigrade higher than that in the field, and this difference is well within the reported deviation of 3 degrees centigrade. This conclusion is valid for wet ducts, which constitute the majority of existing ducts. For dry ducts the error caused by radiation is certainly larger.

Convection

A certain amount of heat is transferred across the duct space by means of free convection. There are empirical equations,[1,6] that permit approximate computations. H_c, the heat transferred per unit length by convection from a pipe to air, is given by

$$H_c = k a^{3/4} (T_s - T_d)^{5/4} \qquad (21)$$

where k = a constant depending on the ratio of cable radius to duct radius; for the present case, $k = 2.7 \times 10^3$ absolute units.

In order to check the influence of convection on the sheath temperature, the free convection normally active around the sheath was increased by forced convection. This was obtained by forcing nitrogen longitudinally through the duct. If V denotes the rate of flow of the nitrogen, ρ_N its density, c_N its specific heat, and ΔT the temperature differential along the duct, then the heat removed per unit time from the sheath by way of forced convection, H_{fc}, is given by

$$H_{fc} = V \rho_N c_N \Delta T \qquad (22)$$

V and ΔT were measured, and H_{fc} calculated from equation 22. The rate of flow, V, was adjusted so that H_{fc} equalled approximately twice the value of H_c (known from equation 21) times the length of the duct. The sheath temperatures measured before, during, and after applying the forced flow gave an indication of the influence of convection on the temperature distribution.

Table II shows the data obtained on two loads: 11.8 and 18.9 watts per foot,

Table II. Sheath Temperatures, T_s, for Different Conditions of Convection

	Load = 11.8 Watts Per Foot		Load = 18.9 Watts Per Foot	
	Free Convection Alone, 5 Watts	Forced Convection Superimposed, 8.5 Watts	Free Convection Alone, 8.5 Watts	Forced Convection Superimposed, 19 Watts
Before forced convection	59	—	84	—
During forced convection	—	59.5	—	83
After forced convection	60	—	83	—

with the duct dry. T_s for the two loads is 59 and 84 degrees centigrade; T_d is 37 and 51 degrees centigrade respectively.

It can be seen that the influence of a forced convection, amounting in terms of heat loss to about double that for free convection, is practically negligible. As before, in the case of radiation, this result refers to the model only and does not give specific information as to a divergence between field and model data caused by a possible difference in convection. This difference, however, can be estimated from equation 21.

Considering the medium load, 11.8 watts per foot, the value of H_c, the heat dissipated by way of convection, for the field and the model respectively, is 0.3 and 0.1 watt per foot, that is three and one per cent of the total. In contradistinctiou to radiation, which amounts to appreciable percentages of the total heat dissipated—without, however, affecting correct duplication of the field test by the model—convection amounts to only a small percentage of the total heat dissipated. The effect of this small amount, being reduced in a ratio of one to three in the model as compared with the field, has certainly no influence upon the duplication of the sheath temperatures.

Water in Ducts

As a last additional test, the question of the amount of water that is required to make a wet duct out of a dry duct was investigated. In comparing sheath temperatures shown in Table I (dry duct) with those shown for the model test in curve 2 of Figure 6 (wet duct), it can be seen that a dry duct results in sheath temperatures higher than those in a wet duct. It was important to find out how much water should be introduced in the model duct in order to approximate field conditions. From physical considerations it appeared that a certain minimum amount is required in order to establish a conducting path of water between the cable and the bottom of the duct wall and that further additions of water should have little effect. Table III gives the results of a test, referring to a load of 18.9 watts per foot, in which increasing amounts of water were added to the duct containing the test cable. It can be seen that for the model, small amounts of water (ten cubic centimeters) were sufficient to bring the temperature of the sheath from 83 degrees centigrade down to 65 degrees centigrade. It appears that ten cubic centimeters is sufficient to cause an appreciable drop in temperatures and that 50 cubic centimeters is sufficient to insure the formation of a complete conducting path along the length of the model duct and to bring the temperature level down to 60 degrees centigrade, which was the level as measured in the main test and also in the field. Further additions of water change the temperature only slightly. The equivalent amount of water present in a wet duct in the field is then at least $10 \times 21.2/15 = 14$ cubic centimeters per foot.

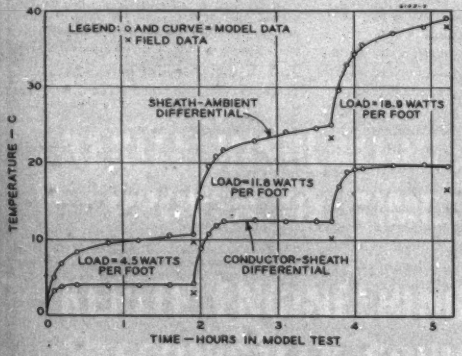

Figure 7. Temperature differentials between sheath and ambient, and conductor and sheath for a 3-conductor model cable

Installation and load schedule is the same as indicated in Figures 5 and 6. Field data for the conductor are equilibrium values

Model 3-Conductor Cable in Duct Bank

The tests described in the two preceding sections were carried out with a single-conductor cable, and accordingly conductor temperatures were not comparable with those in the field because the field tests involved 3-conductor cables. In order to fill this last gap in the research, it was necessary to have a model of the 3-conductor 350,000-circular-mil cable used in the field. Through the courtesy of Doctor R. J. Wiseman, the Okonite Callender Cable Company manufactured such a cable according to developed specifications.

The cable was constructed according to the following design. The conductor was number 8 American Wire Gauge wire having an over-all diameter of 0.147 inch, which is, as pointed out previously, 4.6 times less than the conductor of the high-voltage cable. One of the three conductors was a copper tube of an outside diameter of 0.156 inch and a wall thickness of 0.032 inch; the cross-sectional area of the tube was nearly identical with that of the stranded wire. The purpose of the tube was to accommodate the thermocouple for conductor temperature measurements. The insulation

Table III. Sheath Temperatures, Degrees Centigrade, for Increasing Amounts of Water in Duct

Load = 18.9 Watts Per Foot	
Amount of Water, Cubic Centimeters, in 15-Foot Duct Containing Test Cable	Sheath Temperature, Degrees Centigrade, of Test Cable
0	83
10	65.5
20	57 (?)
30	67
40	65.5
50	62
60	60
70	61
80	62
100	60.5
120	59
140	58
200	59.5

thickness was 0.31/4.6=0.068 in. The outermost layer was metallized paper. In order to compensate for the larger outside diameter of the tube, one layer of paper was omitted from its insulation. Fillers of suitable size and a binder tape made of 4-mil copper were used. (A copper tape of reduced thickness, say, 2-mil, is more advisable.) The lead sheath was 2/64 inch thick, and the over-all diameter obtained was 0.69 inch, which is close to the theoretically correct 0.68 inch, that is, 3.1/4.6.

The single-conductor cable used as test cable in the last test described (Figure 6) was then replaced by this model cable, and the same load cycle schedule applied, except that for the sake of simplification the duration of the cycles was not more than about two hours each. This was sufficient in this case, since the main interest of this test centered around the sheath-conductor temperature differential, and this reached its final value in about that time.

The results of this test are reproduced in Figure 7. Both sheath-to-ambient and conductor-to-sheath differentials are shown. The corresponding field data for the conductor refer to equilibrium values as obtained at the end of each load period.

While the sheath temperatures are in rather good agreement with those in the field, the discrepancy for the conductor-sheath differential is somewhat larger, up to three degrees centigrade. This difference is partly inherent, inasmuch as the insulation structure, and therefore the thermal resistivity, for a real and a model cable cannot be made strictly identical. Part of the difference, however, is caused by uncertainties and difficulties in the measurement of copper temperatures in the field (obtained from the electrical resistance of the conductor). A deviation of up to three degrees centigrade, nevertheless, is not objectionable from a practical standpoint.

In closing, a few remarks concerning end-effect are in order. Since these tests were carried out with the idea of later developing the method into a practical one, it was tried to keep it as simple as feasible; no attempt was made, therefore, to compensate for a possible end-effect. In order to ascertain whether or not an appreciable error is introduced on this account, the last test with the model cable was used also for the measurement of the magnitude of this effect. A thermocouple was inserted into the tube, about six inches inside the end walls of the box. At the end of the first load period, the end was cooler by one degree centigrade than the center; at the end of the second load, the end was warmer by two degrees centigrade than the center; and at the end of the third load, this difference increased to six degrees centigrade.

An approximate calculation shows that these differentials are not likely to lead to an appreciable error. From the dimensions of the cable and the thermal resistivity of copper, the thermal conductance of the three conductors from both ends to the center is found to be 0.0013 watt per degree centigrade. For the worst case (the third load) the heat that flows toward the center is only 0.008 watt. Even with the conservative estimate that this heat is dissipated along a length of, say, only one inch, for which the load is 1.6 watts, the error is only one-half per cent, and thus is negligible.

Conclusions

The present research shows that a reduced scale model installation can be used successfully for determining cable temperatures and hence maximum permissible loads, both normal and overload. Such an installation is meant to be used as a laboratory tool, just as any other measuring device. Its chief use probably will be found in cases of several cables in a duct bank, each cable having a different prescribed load schedule. By reproducing any desired cable and load combination in the model, a reliable answer to any specific problem can be obtained in a relatively short time.

References

1. Establishment of Cooling Curves of Welds by Means of Electrical Analogy, Victor Paschkis. *Welding Journal*, October 1943, page 463-s.

2. Operational Methods in Applied Mathematics (book), H. S. Carslaw, J. C. Jaeger. Clarendon Press, Oxford, England, 1941. Page 109.

3. Operational Methods in Applied Mathematics (book), H. S. Carslaw, J. C. Jaeger. Clarendon Press, Oxford, England, 1941. Page 128.

4. Current Rating of Cables for Transmission and Distribution, S. Whitehead, E. E. Hutchings. Institution of Electrical Engineers, London, England, volume 83, 1938, pages 551-2.

5. Tables of Functions (book), E. Jahnke, F. Emde. Dover Publications, New York, N. Y., 1943. Page 6.

6. Elements of Heat Transfer and Insulation (book), Max Jakob, G. A. Hawkins. John Wiley and Sons, Inc., New York, N. Y., 1942. Page 125.

7. Heat Transmission, T. B. Drew, H. C. Hottel, W. H. McAdams. *Transactions*, American Institute of Chemical Engineers, volume 32, 1936, page 271.

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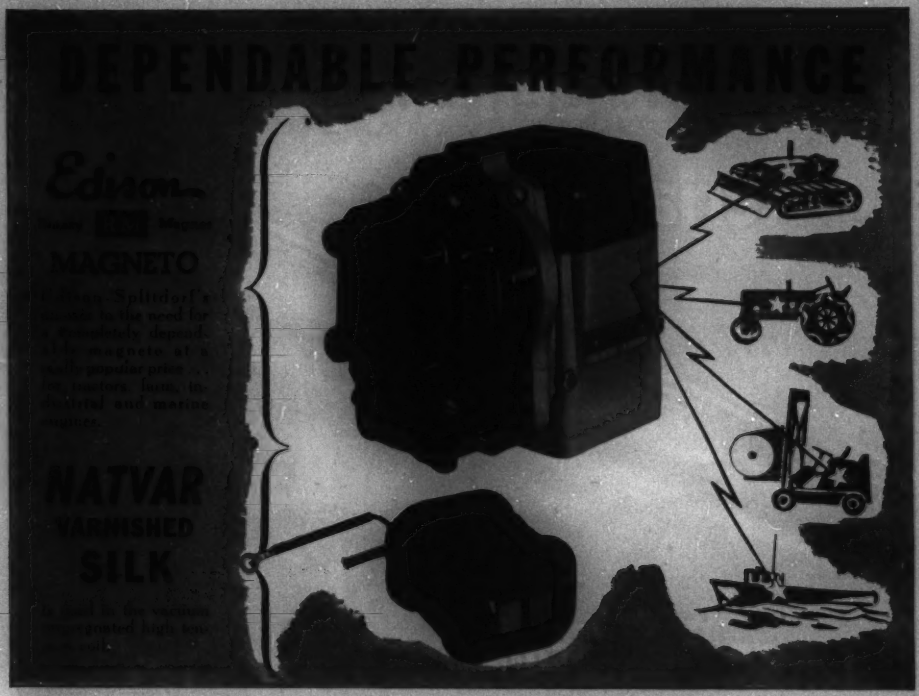

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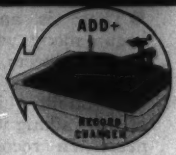

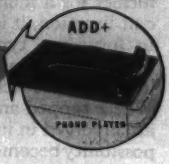

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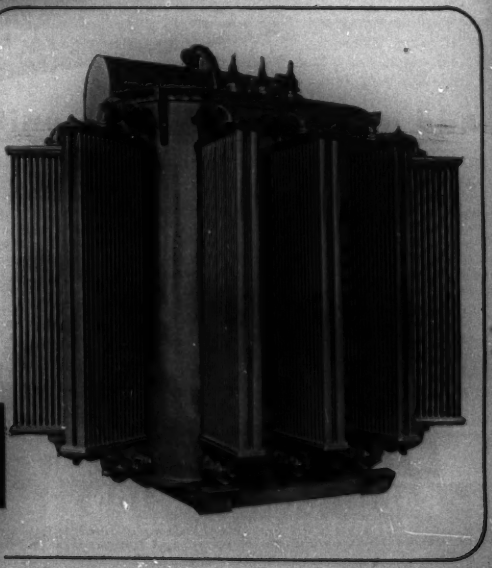

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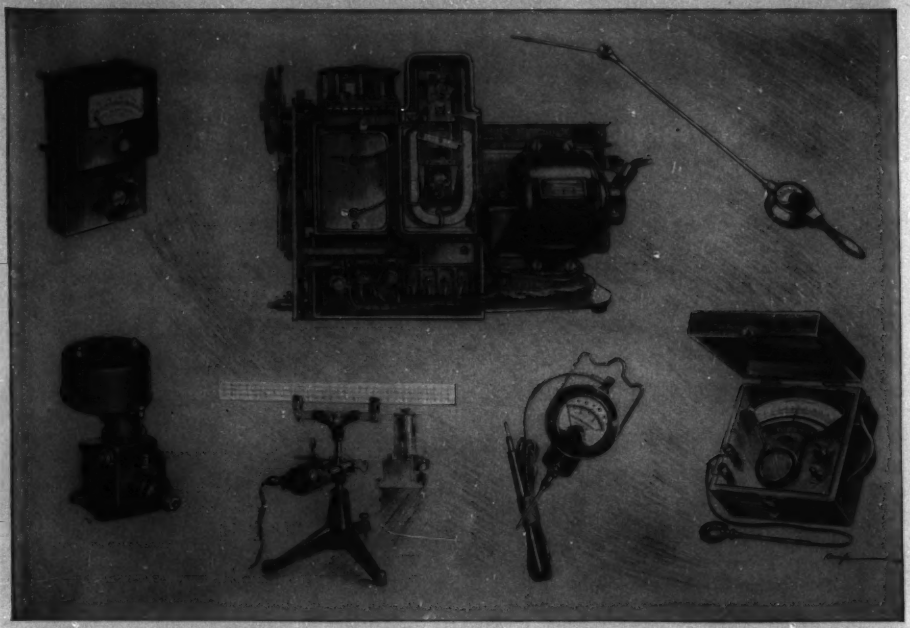

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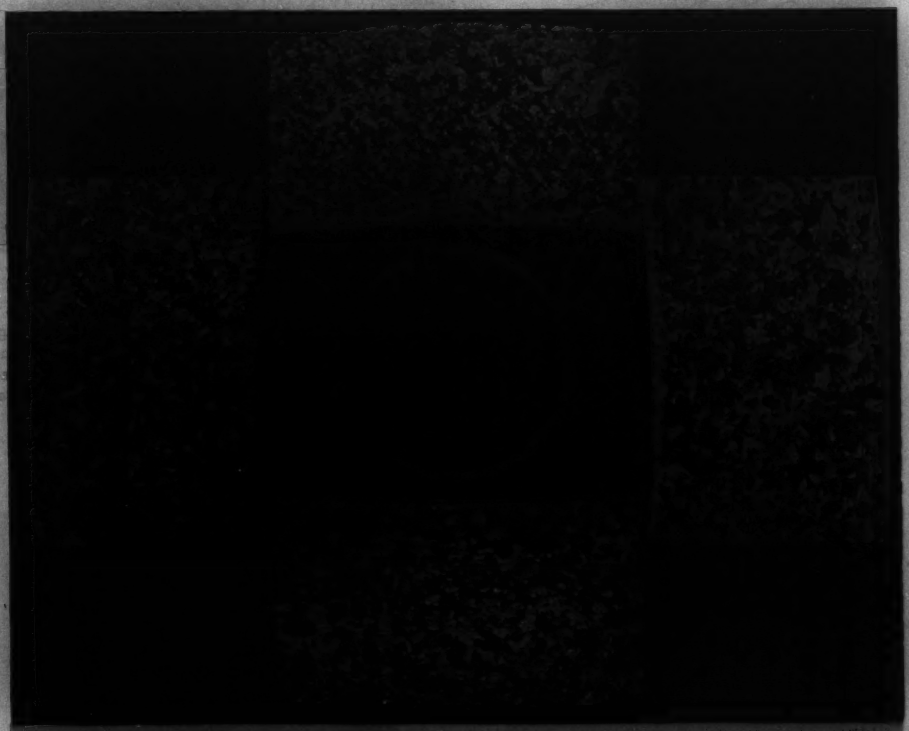
A NEW

CABLE SHEATH... ANACONDA F-3 ALLOY



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High Resistance to Bending Fatigue

Low Creep Rate — High Burst Strength

Non Age-Hardening — Superior Welds

High Resistance to Stress-Cracking

Exceptional Toughness Combined with Hardness and Strength

NOMINAL COMPOSITION

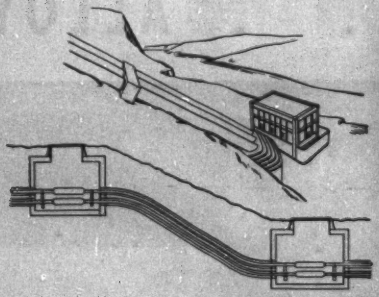
An Arsenic-Lead Alloy*, containing nominally 99.65% lead, heat treated to further improve superior physical properties.

*U. S. Pats. 2,300,788, 2,375,733.

Anaconda F-3 Alloy Cable Sheath

Resistance

RADIAL

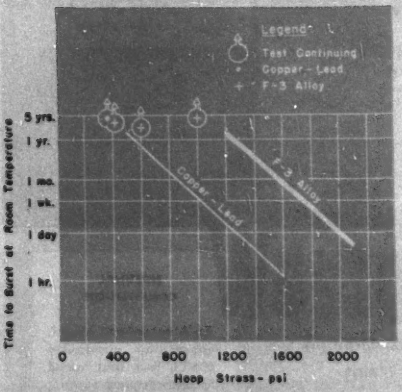


Like the penstock of a hydro-plant, the lead sheath of oil-impregnated paper cable, when installed on a slope, is subject to hydrostatic pressure due to the head of oil. In the case of cable this is augmented by daily expansion and contraction caused by loading cycles.

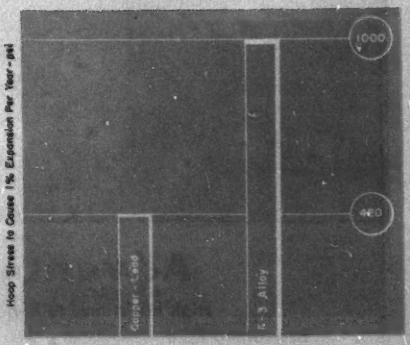
This action causes the cable sheath and joint sleeves to gradually expand, and eventually burst. Ability of cable sheath to withstand such stresses is determined by "bursting" tests, and by "creep" tests.

Reference No. 3, Fig. 1

"Bursting" and "creep" tests of lead sheathing are conducted by subjecting samples to a constant internal pressure at specified temperatures and observing the *time* to burst, or the *rate* of creep, or flow of the metal.



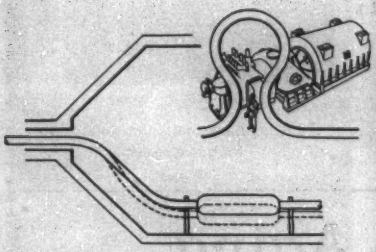
F-3 Alloy is more resistant to bursting than other lead-sheath alloys.



The creep characteristics of F-3 Alloy are equal or superior to those of any other lead-sheath alloy.

to Stress

BENDING



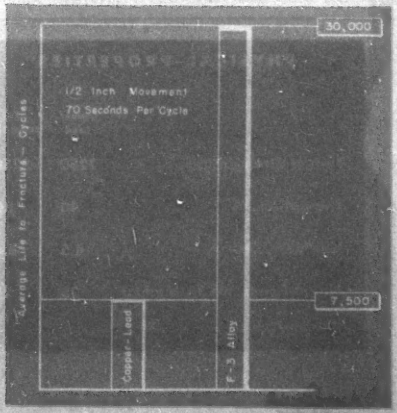
Reference No. 2, Fig. 11

As in the case of expansion loops in steam pipes, the power cable is provided with an "expansion loop" in each manhole. Expansion and contraction due to daily load cycles flex the cable causing bending stresses in the sheath.

One test simulating this flexing is the "dummy manhole" test.

Apparatus for conducting life tests on cables in a dummy manhole. The flexing simulating operational conditions is done mechanically.

Typical failure of specimen subjected to dummy manhole test.

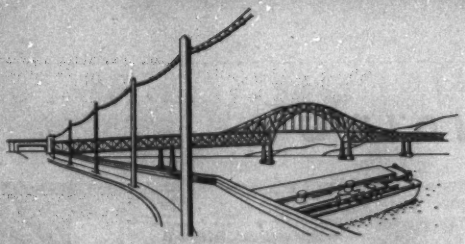


Tested by a Large Utility

Equivalent "Life" tests demonstrate superiority of F-3 Alloy.

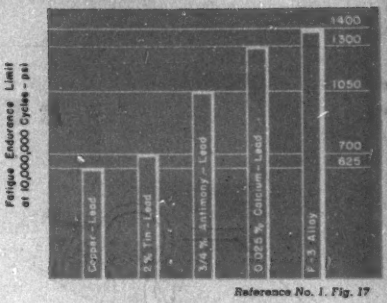
Anaconda F-3 Alloy Cable Sheath

Resistance to Fatigue



Cables installed aerially, on bridges and in ships are subject to vibrational fatigue, and in some instances to ring cutting.

Tests of cable-sheath alloys indicate the high quality of F-3 Alloy in resisting such stresses.



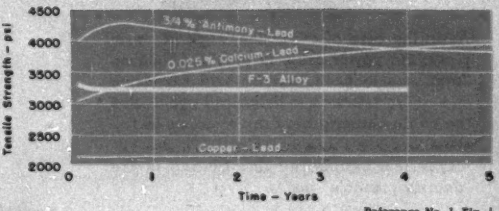
Reference No. 1, Fig. 17

F-3 Alloy has excellent resistance to fatigue stresses.

Resistance to Aging

F-3 ALLOY DOES NOT AGE-HARDEN

Therefore, it retains its superior bending, creep and fatigue properties throughout its useful life.



Reference No. 1, Fig. 1

PHYSICAL PROPERTIES*

	Copper-Lead	F-3 Alloy-Lead
Tensile Strength, psi	2250	3250
Elongation, %	40	30
Hardness, Brinnel	4.5	8.4
No. of Bends, IPCEA Method	35	25

*Tube Specimens

REFERENCES

1 "F-3 Lead Alloy—An Improved Cable Sheathing," L. F. Hickernell and C. J. Snyder. AIEE Summer Convention, Detroit, Michigan. June 26th-30th, 1946. (Paper 46-115)

2 "Load Ratings of Cable," Herman Halperin. AIEE Transactions, Vol. 58, 1939, page 535.

3 "The Testing of Lead Cable Covering," W. H. Bassett, Jr. and C. J. Snyder. ASTM Proceedings, Vol. 40, 1940, page 910.

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The *-hp-* Model 410A is the instrument the whole electronic industry has been looking for. Your early inquiry will be first assurance of prompt delivery. Write today for more complete information — prices — delivery dates.

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ac Measurements

Six ranges, full scale readings 1, 3, 10, 30, 100, and 300 volts.

Input impedance, 6 megohms in parallel with 1.3 uuf.

Frequency response, 20 cps to 700 mc ± 1 db.

dc Measurements

Seven ranges, full scale readings 1, 3, 10, 30, 100, 300, and 1000 volts.

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Get in touch with your nearest Regional Office of the War Assets Administration. Special technical personnel will be happy to give you data on specific types and sizes or arrange for your inspection of the material.

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Filament Current	27.5 amps.
Maximum Ratings for Maximum Frequency of 50 Mcs	
DC Plate Voltage	4500 volts
DC Plate Current	1.25 amp.
Plate Dissipation	2500 watts
Overall Height	App. 7 inches
Maximum Diameter	3½ inches
Supplied with 6" flexible copper leads, 2 on each terminal.	
Type of Cooling	Forced-air

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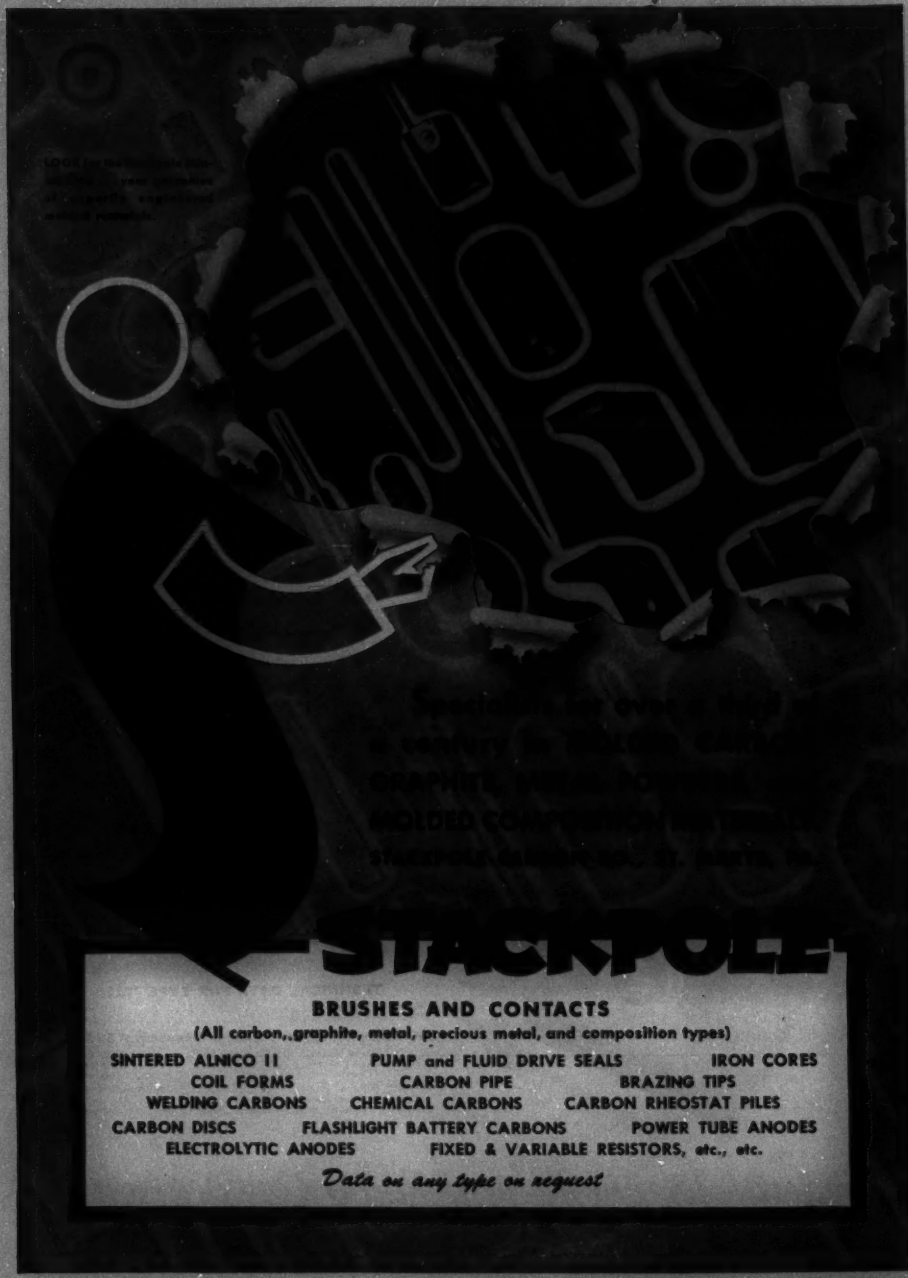

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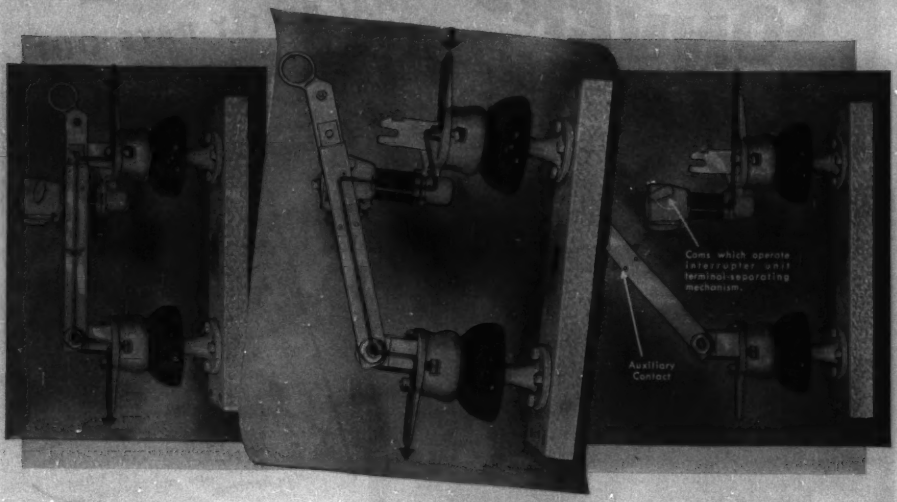


HOW IT OPERATES

To interrupt the circuit, switch is opened in conventional manner and at normal speed. During this operation an air-gap is established between switch blades and contact clips, and current is shunted through the load interrupter unit by means of a spring-operated, auxiliary contact on the main blade assembly, bearing against the load interrupter housing. Progressive movement of the switch blades actuates a spring mechanism in the load interrupter unit, separating its terminals at snap speed. Separation of these terminals in the course of switch operation lengthens the arc, which is extinguished between insulating surfaces productive of vapors favorable to arc-extinction.

Arcing time is very short, depending upon voltage, load current, and power factor. The circuit interrupting operation is completed before auxiliary contacts on the switch blades are broken at the load interrupter unit housing.

S & C Load Interrupter Switches provide modern load-switching with important advantages for electric utilities and large industrial users. The fact that they interrupt all load currents with the arc wholly contained within the interrupting unit contributes these highly desirable characteristics:

1. **Suitable for use indoors or outdoors — in cubicles or open.**
2. **Minimum space requirements — particularly important in cubicles.**
3. **Satisfactory operating life with a minimum of maintenance.**
4. **Contributes to convenience and safety in operation.**

When short-circuit protection is supplied by S & C Type SM, high interrupting capacity power fuses in combination with S & C Load Interrupter Switches, this equipment is often suitable for installations formerly requiring much larger and costlier equipment.

S & C engineers and builds the job complete. Ask for list of satisfied users . . . together with new Bulletin 202A.

Schweitzer & Conrad, Inc.
Ravenswood Avenue, Chicago 40, U. S. A.
Represented in Principal Cities (Consult Telephone Directory)
In Canada by Powerlite Devices, Ltd., Toronto, Ont.

"Give Me Metal-Clad Switchgear With These Three Advantages . . "

Yes, Most Operators have Three Chief Requirements for Switchgear, and All Three Needs are Met in Full by Allis-Chalmers Advanced Design

DETAILS which contribute to *easy maintenance* of Allis-Chalmers switchgear units are removable plates for access to instrument compartments, etc; "hinged" wiring connection to eliminate wear or bending on wires when door is opened or closed; and special method of insulating busbars without necessity for using compound-filling for bus joints.

Isolation of units, fully automatic disconnect shutters, and positive interlocks on elevating mechanism are a few of the details adding up to *safety* for operators.

Completely factory-built, wired and assembled, Allis-Chalmers switchgear units are *easy to install*. Simple four-point alignment saves installation time!

Allis-Chalmers metal-clad switchgear is equipped with magnetic air, oil, or air blast circuit breakers. For details, see your nearby A-C office, or write ALLIS-CHALMERS, MILWAUKEE, WIS.

A 2091

ALLIS AC CHALMERS

One of the Big 3 in Electric Power Equipment — Biggest of All in Range of Industrial Products

METAL-CLAD *Switchgear*

FUSE PROTECTION

As a built-in component of the newly designed 2 KVA POWERSTAT variable transformers*, the fuse in the output brush contact lead offers economies in set-up time and replacement costs. Needless to say — replacing fuses is decidedly less expensive than replacing POWERSTATS. But . . . instrument protection is not the only new feature of the fused POWERSTATS. User protection is also incorporated. A totally enclosed aluminum terminal box houses all "hot" connections. With the input cord-plug and output receptacle combination, anyone can operate a POWERSTAT without danger of personal injury.

OUTPUT RECEPTACLE

To suit each requirement, the output receptacle is available in a variety of types. It can be supplied to accommodate a two or three wire — straight blade or twist-lock type plug. Connection of the load is a simple matter. There is no bother of clip-leads or direct wiring.

FUSE PROTECTION

Although the fuse has been so selected that the maximum rated current can be drawn at any dial position, it opens the circuit immediately when this value is exceeded. Burned-out coils and ruined brush contacts from overloading are a virtual impossibility. Situated in the recessed bottom portion of the durable cast-aluminum terminal box, the cartridge type fuse can be removed with very little effort. It is protected by a cast-aluminum section which is held in place by screw-connection.

INPUT CORD AND PLUG

Logically, the input cord and plug is a duplication of the output receptacle 2 or 3 wire — straight blade or twist-lock arrangement. In the 3 wire system the 3rd wire is solidly grounded to the POWERSTAT frame. By plugging the cord into a convenient outlet, the POWERSTAT is ready for use.

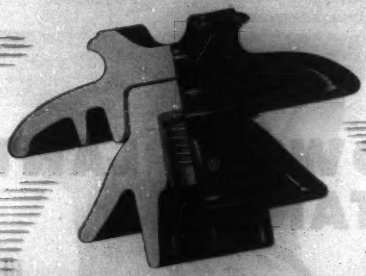
* Write factory for further details on either terminal stud or fused type POWERSTATS.

Send for Bulletins EE

THE SUPERIOR ELECTRIC COMPANY

807 LAUREL STREET, • • • BRISTOL, CONNECTICUT

O-B PINTYPES KNOW HOW TO "Roll with the punches"



WHEN LIGHTNING STARTS to ground, a pintype insulator on top of a pole is scarcely more than a fly speck in the way of such a vast rush of power. Two things can happen. The insulator can be destroyed or it can "roll with the punch" and survive; ready to go along with its regular duties, for which it is adequate.

Under the extremely steep wave fronts known to exist in some lightning discharges, flashover does not take place fast enough to prevent a brief but tremendous electrical stress falling on the porcelain. A good pintype insulator must withstand this. It calls for "plenty of insulator" skillfully designed.

The presence of these desirable qualities in an insulator is not obvious. You can't find them just by looking for them--you must *know* they are there; and putting them there is a function of intelligent insulator manufacture.

Sound design, and an ability to make them *right*, has saved the life of many an O-B pintype insulator and saved a lot of trouble and expense for its owner. Pintypes look alike - granted - but over a period of years their behavior is *anything but alike*. For top performance, build with O-B!

2650-H

Ohio Brass

MANSFIELD, OHIO

CANADIAN OHIO BRASS CO., LTD., NIAGARA FALLS, ONT.

HEADQUARTERS FOR PORCELAIN INSULATION

FLOATING POWER PLANT "RESISTANCE"

For Sale

GOVERNMENT OWNED
SURPLUS PLANTS

The War Assets Administration invites proposals for the purchase of this floating, steam-electric power plant, constructed for War Emergency use and now declared surplus to the needs of the War Department.

Philadelphia, Pennsylvania (Plancor 525).

Contained in an ALL-WELDED SEA GOING HULL, suitable for towing from one location to another, this modern high-pressure, high temperature Power Plant is designed to operate at either 50 or 60 cycles, and at an efficiency comparable to a modern high-pressure stationary power plant.

With a 50 foot beam, 358 foot length, 9½ foot draft, and 28 foot height with smoke stacks and transmission towers removed, the dimensions of the Hull permit passage through locks of standard size and under low bridges on inland waterways. Seven days fuel oil storage, based on operation at full capacity, is provided for.

MACHINERY AND EQUIPMENT include: Turbo-Generator: General Electric, 3 phase, 13.8 KV, 3,600 RPM, 19 stage, 825 psi gauge, 900° F, with capacity of 30,000 kw at 60 cycles and .8 power factor, or 25,000 kw at 50 cycles and .9 power factor. Equipped with Elliot condensers using either salt or fresh water.

Boilers: 2—Babcock and Wilcox, 170,000 lbs. per hour each, at 835 psi gauge, and 910° F. Equipped to burn fuel oil or natural gas.

Auxiliary Power Units: 2—300 kw Diesel engine generator sets, 480 volts AC, 3 phase, 60 cycles. Ingersoll Rand engines and General Electric generators.

Substation: Westinghouse 37,500 KVA, 13.8 KV transformer with taps for 132—126—120—112—109—69 and 63 KV.

CREDIT TERMS MAY BE ARRANGED FOR THE PURCHASE OF THIS PLANT

All data contained herein are necessarily abbreviated, and subject to correction. They are not intended for use as a basis for negotiation. For more complete information contact the office indicated below. WAR ASSETS ADMINISTRATION reserves the unqualified right to reject any or all proposals or offers received for the above property.

Address your inquiries or proposals to:

Utilities Branch—Industrial Division
OFFICE OF REAL PROPERTY DISPOSAL

WAR ASSETS ADMINISTRATION

WASHINGTON 25, D. C.
PHONE: REPUBLIC 7500, EXTENSION 3664

604T

"Must be somethin' he et!..."

THERE'S ALWAYS A GOOD REASON why one kid shoots up faster than all the others in the neighborhood. It isn't luck. Most likely, it's more vitamins, more sunshine and better care.

Companies like Cornell-Dubilier don't grow up overnight either. Experts like C-D engineers don't just "happen". Only here it isn't what you *eat* or *dream;* it's what you *do*. You dig behind what others have told you. That's research. You look beyond what others have seen. That's pioneering. You spend more time and money, than might seem immediately profitable, to become proficient in your field. And when the "unheard of" has to be done, industry expects you to do it.

When giant capacitors, that could handle severe temperatures without the use of water-cooling coils, were needed, they came to Cornell-Dubilier. And when capacitors were needed for the Proximity Fuze, in sizes so tiny they had never before been envisioned, C-D engineers were handed the problem.

Remember that when your plans call for the unusual in capacitor design and dependability.

★ ★ ★

Cornell-Dubilier Electric Corp. South Plainfield, New Jersey. Five other plants in New Bedford, Brookline, Worcester, Mass. and Providence.

CORNELL-DUBILIER

world's largest manufacturer of

CAPACITORS

MICA • DYKANOL • PAPER • ELECTROLYTICS

DC

DOW CORNING

SILICONES

FLUIDS

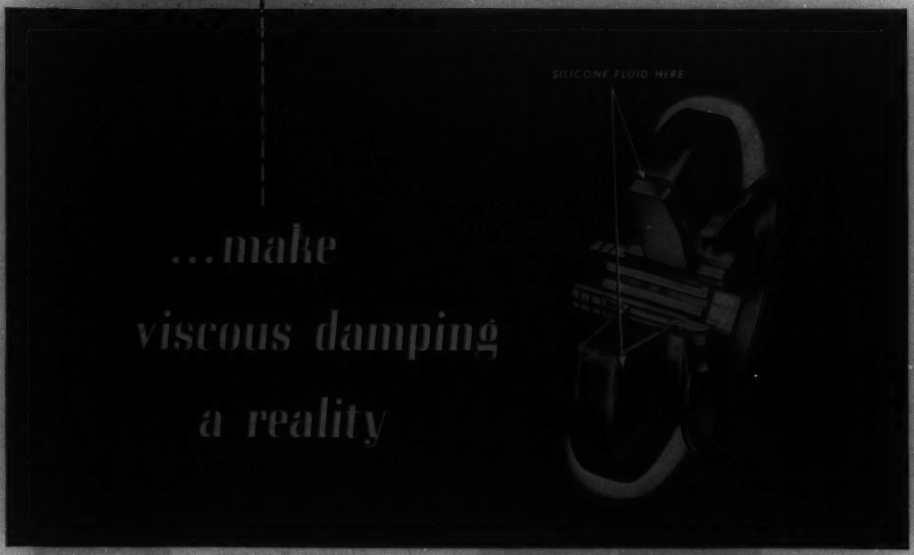
VARNISHES

RESINS

GREASES

SILASTIC

retain their essential properties over a very wide temperature range



High viscosity DC Silicone Fluid makes possible this simple, durable Torsional Vibration Damper for automobile and Diesel crankshafts, developed by Houde Engineering Division of Houdaille-Hershey Corporation. Inner flywheel, separated by a film of DC Silicone Fluid from housing attached to end of crankshaft, tends to rotate at constant speed. Vibrations are damped by shear resistance of silicone film.

DC Silicones are new engineering materials now available to give commercial reality to engineering principles never before practical. Viscous damping is an old principle—now brought into practical utility through the use of silicone fluids. Here, as in many industrial problems, the solution lay in a combination of properties possessed only by these materials: singularly constant viscosity over a wide temperature range; molecular stability despite continuous shearing, mechanical abuse, and high temperatures. DC Silicone Fluids are also water repellent, chemically inert, and electrically non-conducting. Various types are useful as damping and hydraulic fluids, liquid dielectrics, mold release agents, high temperature lubricants, and diffusion pump fluids. For further information, call

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Chicago Office: Builders' Building Cleveland Office: Terminal Tower

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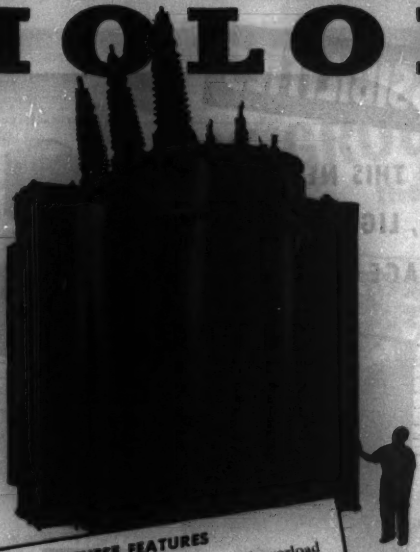
FIRST IN SILICONES

MOLONEY



Power TRANSFORMERS

Research, with our 2,500,000 volt Surge Generator playing an important part, together with 50 years experience in the *exclusive* manufacture of transformers is responsible for the fine operating records users are experiencing with Moloney Power Transformers.

Modern design, workmen of long experience, highest grade material and adequate processing facilities are combined to produce these transformers.

Take advantage of Moloney's wealth of experience and extensive Power Transformer Manufacturing facilities . . . specify Moloney.

✓CHECK THESE FEATURES

High surge resistance and thermal overload capacity. Rigidly braced core-and-coil construction. High-pressure contact tap changers. Sturdily constructed tanks, adequately reinforced. Radiators of all-welded construction.

Distribution TRANSFORMERS

Moloney Conventional Distribution Transformers are widely used on utility distribution systems and in industrial lighting and power applications. Here too, Moloney's engineering and research have combined to make a superior product to fit your needs. Moloney Distribution Transformers are available in capacities from 1½ to 500 Kva, in voltages up to 66,000 volts.

☆ ☆ ☆

Power and Distribution Transformers Exclusively Since 1896

✓CHECK THESE FEATURES

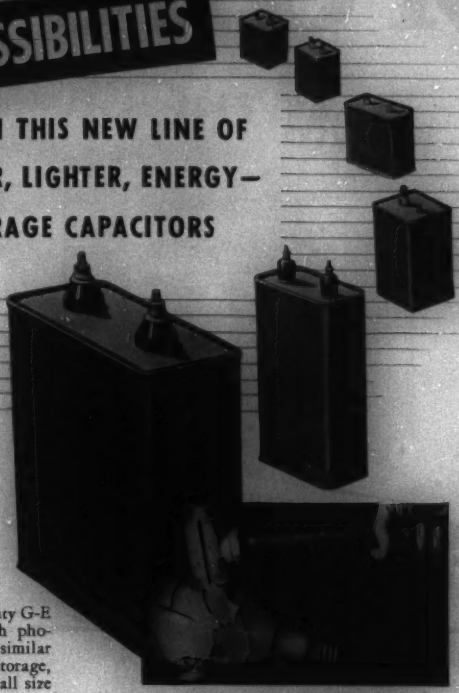
Snap-action, high-pressure contact tap changers with operating handle located above hot oil level. Trouble-free high-voltage bushings. Surge-proven core-and-coil unit. Simplified mounting lugs.

MOLONEY ELECTRIC COMPANY ★ ST. LOUIS 20, MO.

BRANCH OFFICES IN ALL PRINCIPAL CITIES

NEW DESIGN POSSIBILITIES

... WITH THIS NEW LINE OF SMALLER, LIGHTER, ENERGY—STORAGE CAPACITORS



For

High-speed flash photography,
Light-metal welding,
Electronic-timing
devices, etc.

This flash photo was made possible by G-E capacitors.

A complete new line of light-duty G-E Pyranol* capacitors is now available for flash photography apparatus, light-metal welding, and similar applications requiring economical energy storage, fast discharge and service reliability. Their small size and light weight will help designers reduce the size of such equipment.

The high dielectric constant of Pyranol and its high dielectric strength provide outstanding electrical characteristics. Ambient temperature operating limits, at rated voltage, range from 0 to 50 C and the capacitance tolerances, measured at 25 C, are ±10 per cent. The performance of these compact units has been thoroughly proved by several years of laboratory tests and actual operating experience in the field.

G-E light-duty energy storage capacitors are made in a wide range of ratings to fit practically every requirement of high-speed flash photography as well as home and industrial welders of light metals. Careful construction, quality materials, and skillful design contribute to long life and efficient operation.

The accompanying table lists preferred ratings which can be promptly shipped. For further information on these ratings or on designs for special operating conditions, advise us of your problem through *Apparatus Dept., General Electric Company, Schenectady 5, N. Y.*

*Pyranol is G.E.'s trade name for askarel, a noninflammable liquid dielectric.

PREFERRED RATINGS

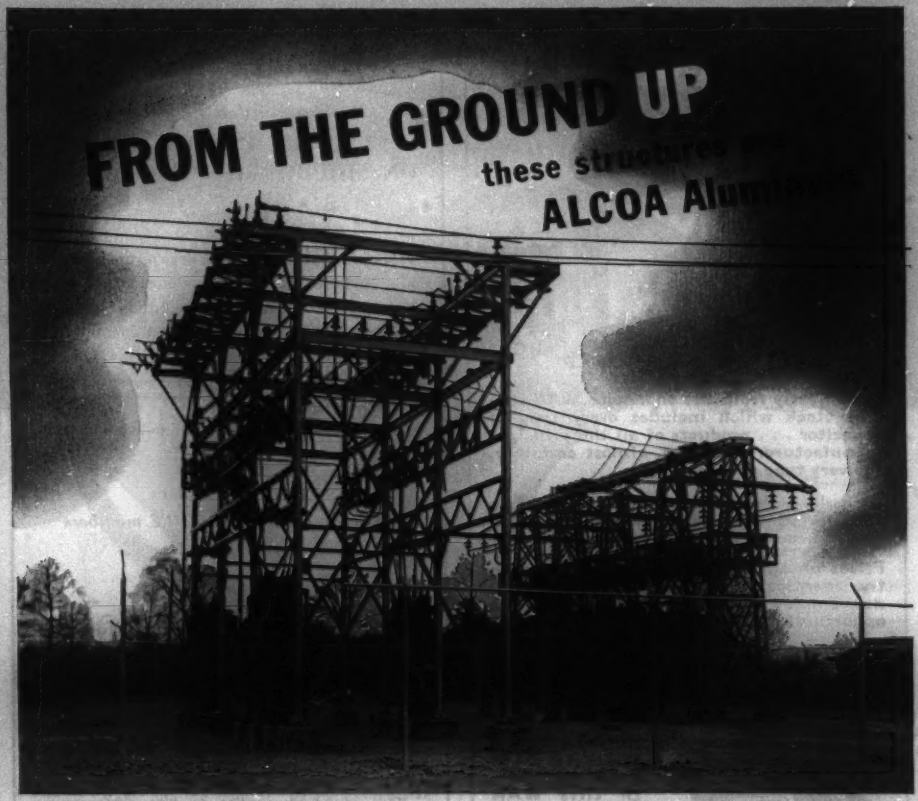
Max. D-C Volts	Mfd	Watt/Sec	Cat. No.	Base	Case Height in In.	Height Over Terminals in In.	No. of Terminals	Net Wt. Lb.
2000	25	50	25F903	A	4 19/32	5 7/64	2	5.2
2000	40	80	25F910	A	7	8 1/4	1	7.8
2500	23.5	80	25F911	A	7	8 1/4	1	7.8
3000	60	270	14F312	B	13 1/8	15 1/8	2	24
3350	17.8	100	25F912	A	7	8 1/4	1	7.8
4000	25/50	200/400	14F309	B	13 1/8	15 1/8	3	26
4000	400	800	14F311	C	12 7/8	15 1/8	2	36
4500	10	100	26F872	A	5 1/2	6 3/4	1	6
5000	25/50	313/625	14F305	D	13 1/8	15 1/8	3	46
6600	55	1200	14F313	C	12 7/8	16 5/16	2	36
7000	25	613	14F314	B	13 1/8	16 5/16	2	26

BASE DIMENSIONS (IN.) A 3 3/4 by 4 9/16 B 4 by 8 C 3 1/8 by 13 1/2 D 4 1/8 by 13 1/2

DISCHARGE *Capacitors*

GENERAL ELECTRIC

407-101-5700



4kv. and 11kv. Powell Avenue substations of the Pennsylvania Electric Company at Erie, Pa. Fabricated by: Railway & Industrial Engineering Company of Greensburg, Pa.

All parts of these structures are nonrusting Alcoa Aluminum. Painting is eliminated, cutting maintenance costs, reducing service interruptions, decreasing hazards.

Lightweight assemblies permit more shop fabrication—less field work—save erection time and costs.

Standard Alcoa Aluminum shapes, plate, bolts and rivets—lightweight, strong, highly resistant to corrosion, readily available—make it possible for you to obtain these advantages in your structures.

For design data and prices, call the nearby Alcoa office. Or write ALUMINUM COMPANY OF AMERICA, 2149 Gulf Building, Pittsburgh 19, Pa.

ALCOA ALUMINUM

We can deliver

ANY CAPACITORS YOU WANT

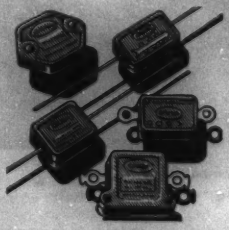
All types, all sizes,

whatever quantity you need,

. . . directly from the enormous WAA surplus stock which includes every type of capacitor . . . products of all the principal manufacturers . . . and, almost certainly, the very type you need.

The quality of these capacitors is equal or superior to commercial standards. All units have passed government inspection to Army and Navy specifications.

Prices on these units, probably including the identical manufacturer's items you now employ in your production, offer the opportunity to gain a measurable saving.



MILLIONS OF MOLDED CAPACITORS—

Mica, silver-mica, and molded oil-paper capacitors in this WAA stock have solved manufacturers' critical shortages.

Liquidation of capacitor surpluses by Tobe Deutschmann Corporation, acting as Agent of the War Assets Administrator, makes huge capacitor stocks *directly available* to the electrical and electronic industries—not as a surplus re-sale . . . with our quarter-century experience, in the production of capacitors for industry, to aid in filling your needs.

Use the enormous stock of WAA surplus capacitors to avoid production hitches and to effect substantial savings!

WRITE . . . WIRE . . . PHONE . . .
FOR IMMEDIATE SHIPMENT

TOBE DEUTSCHMANN CORPORATION

Acting as Agent of War Assets Administrator
Under Contract No. SIA-2-84

Telephone Canton 0820 - Teletype Canton 280
Canton, Massachusetts

STANDARDS

Recommended Practice for

ELECTRIC INSTALLATIONS ON SHIPBOARD—"Marine Rules"

45—1945

These rules have been drawn up to serve as a guide for the equipment of merchant ships with electric apparatus for lighting, signaling, communication, power and propulsion for both alternating and direct current systems. They indicate what is considered good engineering practice with reference to safety of the personnel and of the ship itself, as well as reliability and durability of the electric apparatus.

Price Two dollars

50 percent discount to AIEE members on single copies

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New American Standard for

AUTOMATIC STATION CONTROL SUPERVISORY and TELEMETERING EQUIPMENT

C 37.2—1945

This standard applies to the performance and application of devices when used for the automatic control, supervisory control, telemetering, and supervisory indication of electric power supply or conversion apparatus. It relates to all types of devices for use in automatic switching equipment for controlling unattended or attended generating stations or substations including device function numbers. It does not cover equipment designed for communication circuit switching purposes.

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American Institute of Electrical Engineers

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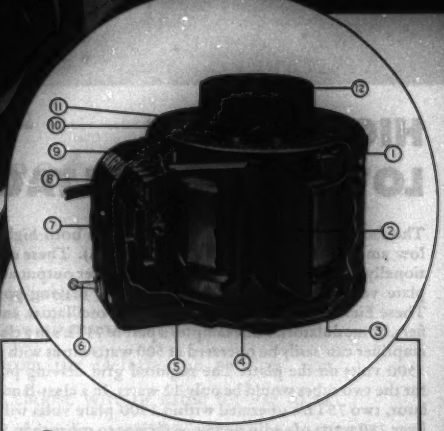
NEW VARIACS with these 12 Features



for

Improved Performance
Greater Convenience
Longer Life

● This new Type V-5 VARIAC replaces the popular Type 200-C. Through entirely new design and radical changes in basic structure the new model is 25% lighter, with the same rating of 860 va. This is achieved both through improved magnetic performance of the core and less copper, and through use of aluminum in most of the structure.

Some of the new VARIAC's many features are listed at the right. Externally, the new VARIAC has been streamlined to eliminate all sharp corners. The cord on the mounted model is arranged to be wound around the VARIAC, plugged into the outlet, and then used as a carrying strap.

This is the first radical change in basic design of the VARIAC since it was introduced by G-R almost 15 years ago. These many changes were made not to dress up the VARIAC in a new case but to provide real improvements to better its performance, increase its convenience and lengthen its life, and to be sure that when you use a VARIAC you are using the best means possible for controlling any alternating-current operated device where perfectly s-m-o-o-th variation in voltage is desired.

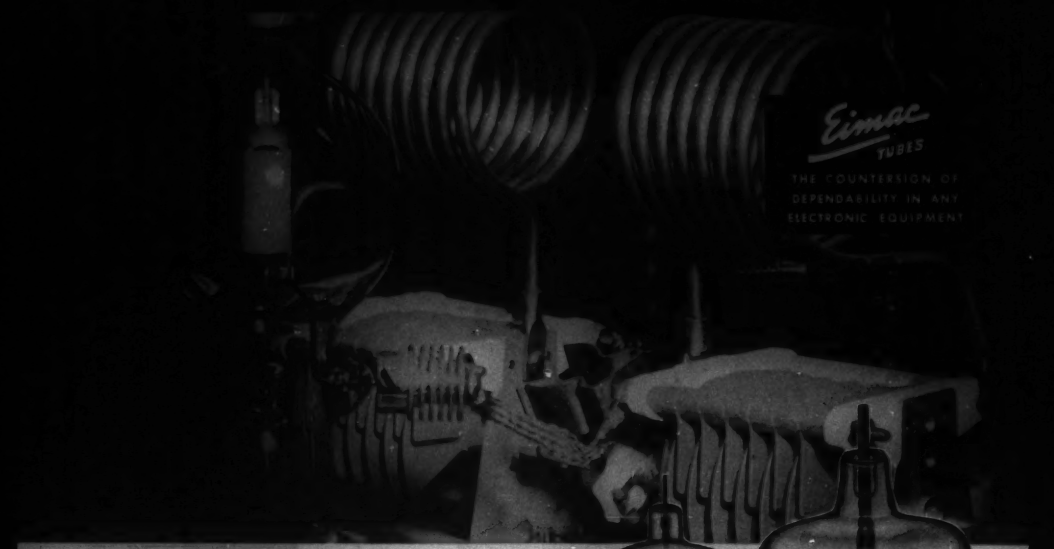
TYPE V-5 860 va VARIAC

TYPE	STYLE	PRICE
V-5	Basic (115-volt input) unmounted model	$16.50
V-5M	Above with protective case around winding	17.50
V-5MT	A V-5 with protective case, terminal cover, 6-foot cord, switch and outlet	20.00
V-5H	Same as V-5, except for 115- or 230-volt input	21.50
V-5HM	Same as V-5M, except for 115- or 230-volt input	22.50
V-5HMT	Same as V-5MT, except for 115- or 230-volt input	25.00

WRITE FOR COMPLETE DATA

1. *New G-R Unit Brush — low sprung weight reduces hammering and arcing under vibration — correct pressure provided by coil spring — holder cannot make contact with winding and cause short-circuit — brush changed quickly without tools.*
2. *New grain-oriented core of cold-finished silicon-steel with guaranteed maximum core loss — strip wound.*
3. *Three rubber feet prevent marring table top and make it unnecessary to screw units down to prevent slippage.*
4. *Aluminum structure contributes to greatly increased output per pound.*
5. *Only two screws hold both case and terminal cover — a screwdriver or a spare dime removes each in a second.*
6. *Heavy-duty switch breaks both sides of the line, in mounted models.*
7. *Polarity indication provided in convenience outlet — useful if one side of line is grounded.*
8. *Improved molded terminal plate protected by a metal, fiber-lined cover — molded barriers between terminals prevent short-circuits from whiskers on stranded wire — both screw and solder terminals — engraved circuit diagram shows normal VOLTAGES between terminals — 2 extra terminals for use with auxiliary transformers.*
9. *New resilient stop allows brush arm to bounce instead of break if you are too vigorous in rotating knob.*
10. *BIG calibration figures and extra points on dial — easy to read at a distance — easier to reset — pointer provided for panel mounting.*
11. *A single screw, readily accessible under dial, loosens shaft for reversing dial and knob to change from table to panel mounting without affecting brush or stop settings.*
12. *Newly designed, larger knob — easier to hold — easier to turn.*

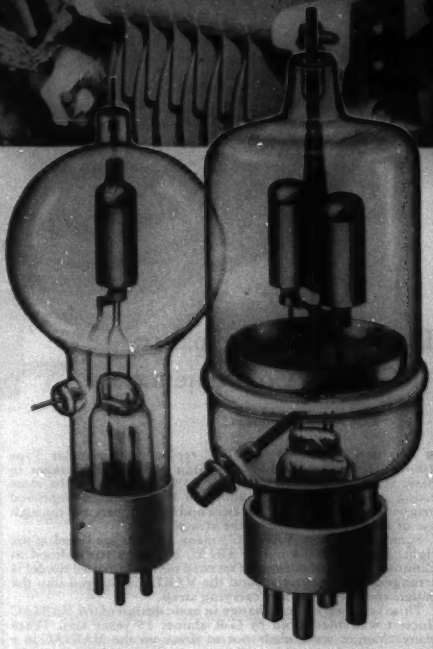
GENERAL RADIO COMPANY Cambridge 39, Massachusetts



HIGH POWER LOW PLATE VOLTAGE

The famous Eimac 75T is now available in both high and low amplification factor types (75TH-75TL). These exceptionally flexible triodes provide a high power output at low plate voltage, and require a minimum of driving power. These Eimac 75T's are suitable for use as oscillators, amplifiers, or modulators. For example: a pair of 75TL's in a class-C amplifier can easily be operated at 500 watts input with only 1500 volts on the plate. The required grid driving power for the two tubes would be only 12 watts. In a class-B modulator, two 75TL's operated within 1500 plate volts will deliver 280 watts of audio power, sufficient to more than 100% modulate the above mentioned RF amplifier.

The Eimac 152T has twice the power handling capacity and twice the transconductance of the 75T, but *less* than twice the already low grid-plate capacity. At 1500 plate volts, 500 watts input can be run to a single 152TL, or a full kilowatt can be run to a pair of 152TL's in a class-C amplifier. For class-B audio, a pair of 152TL's will deliver 560 watts with 1500 plate volts. Eimac 152T's are also available in high and low amplification factor versions. Literature giving full technical information on these triodes available now. Write today, or contact your nearest Eimac representative.



EIMAC 75T
POWER TRIODE

EIMAC 152T
POWER TRIODE

Follow the leaders to

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REG. U. S. PAT. OFF.
TUBES

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Plant Located at San Bruno, California

Export Agents: Frazar and Hansen, 301 Clay Street, San Francisco 11, California, U.S.A.

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ADOLPH SCHWARTZ (W2CN), 220 Broadway, Room 2210, New York 7, New York. Phone: Courtland 7-0011.

HERB. B. BECKER (W6QD), 1406 So. Grand Ave., Los Angeles 15, California. Phone: Richmond 6191.

TIM COAKLEY (W1KKP), 11 Beacon St., Boston 8, Massachusetts. Phone: Capitol 0050.

RONALD C. BOWEN, 1886 So. Humboldt St., Denver 10, Colorado. Phone: Spruce 9468.

JAMES MILLAR ASSOCIATES, J. E. Joyner, Jr. (W4TO) 1000 Peachtree St., N. E., Atlanta, Georgia.

MAXIMUM OPERATING TEMPERATURE

90 C — Type AVB Power Cable (600 volts)

105 C — Limit for Class A (organic) insulating materials — AIEE

110 C — Type AVA Power Cable (600 volts)

125 C — Type AI Power Cable (600 volts)

where TEMPERATURES are on the

HIGH SIDE..

150 C — Recommended limit, Cu Conductors

200 C — AA Asbestos-ASB braid (300 volts)

204 C — GV Glass-Silicone Impregnated

there's a Deltabeston Cable*

built to beat the heat

Wherever wiring must withstand high temperature, you'll find that it pays to check the complete Deltabeston line of heat-resisting wires and cables.

There's a Deltabeston cable to meet the conditions normally encountered around furnaces, soaking pits, and hot strip mills. Other types are built specifically for boiler-room applications, and for jobs that must combine heat resistance with moisture resistance.

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The Standards available are listed below, together with prices. A discount of 50%, on single copies only, is allowed to Institute members (except as noted). Such discount is not applicable on extra copies unless ordered for other members. A binder (illustrated to right) for Standards is available with durable, stiff covers, resembling leather, lettered in gold. Price $1.75 net per binder. Two binders are necessary to hold a complete set of Standards, Reports and Test Codes.

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(Figures in Parentheses Give Dates of Latest Editions)

No.			
	1	General Principles Upon Which Temperature Limits are Based in the Rating of Electric Machinery and Apparatus (June 1940)	$ 0.40
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	3	Guiding Principles for Selection of Reference Values for Electrical Standards (Oct. 1943)	.30
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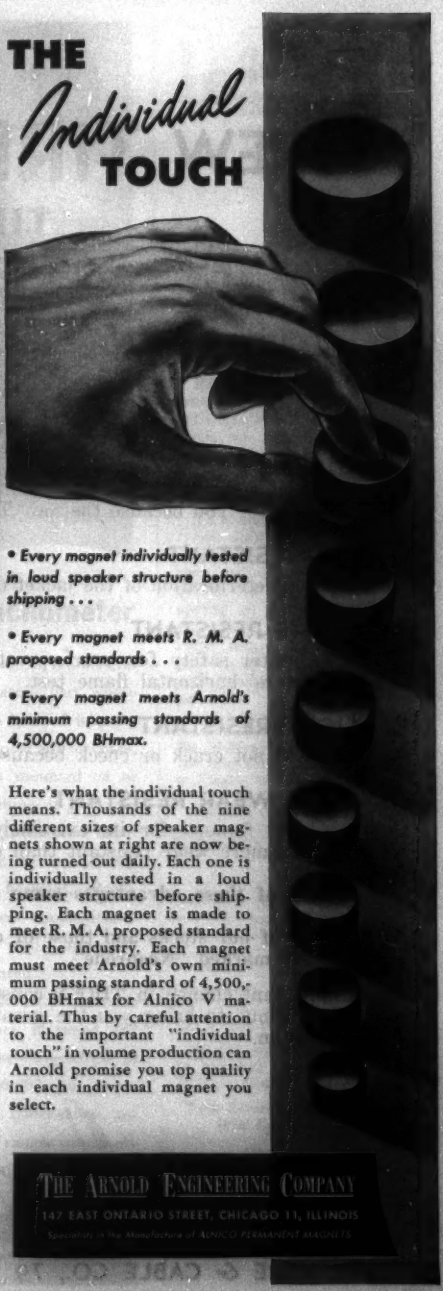

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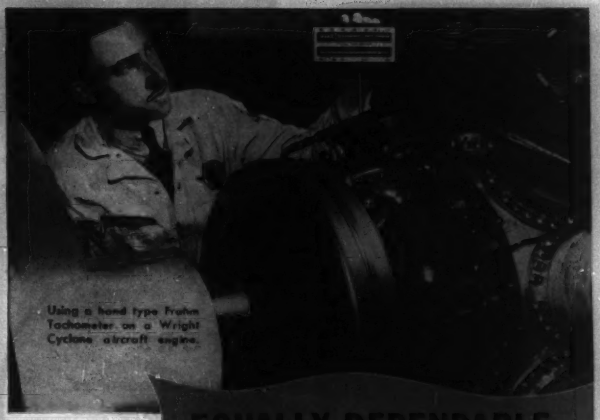

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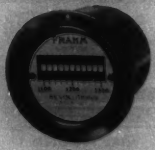

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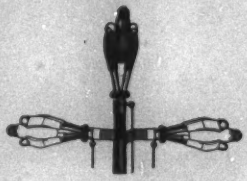

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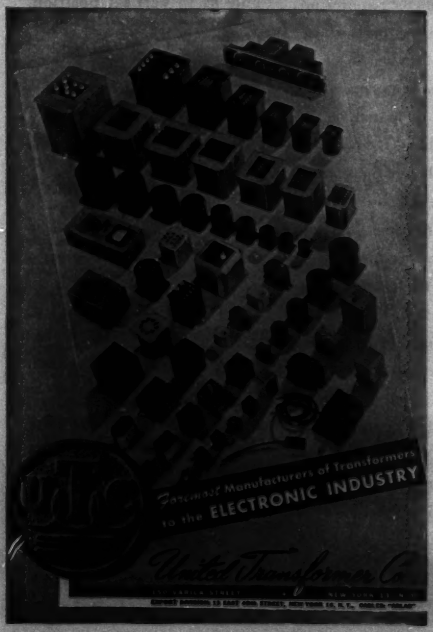

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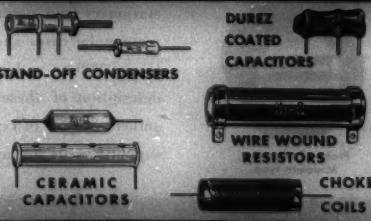

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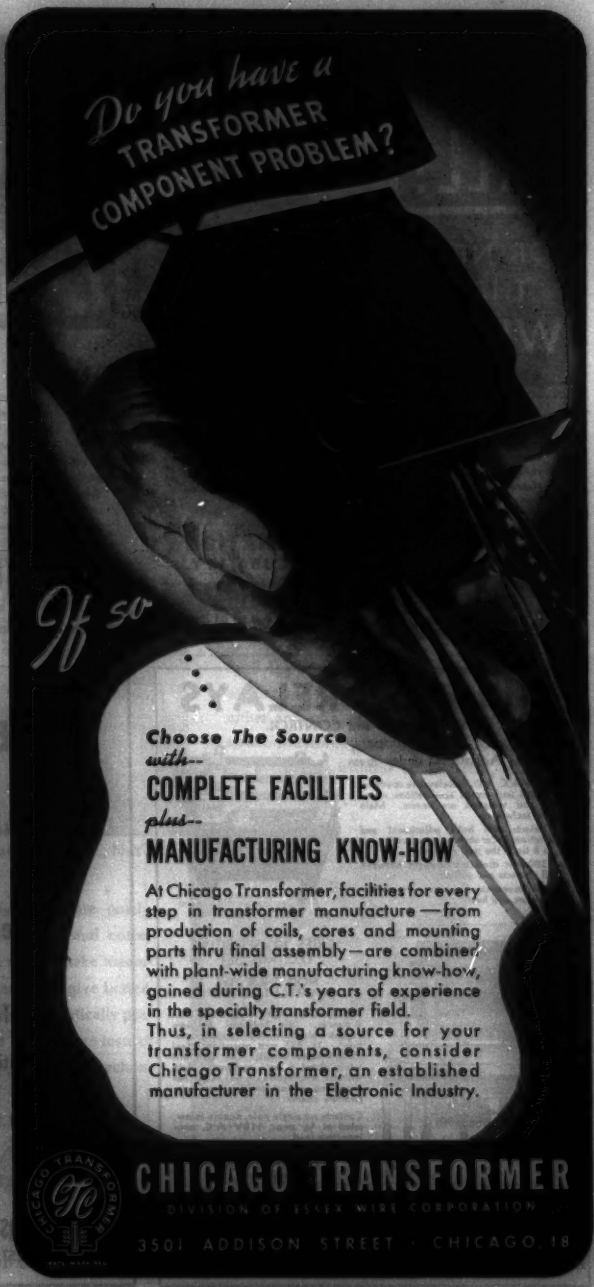

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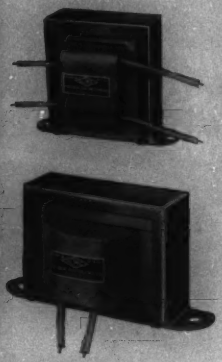

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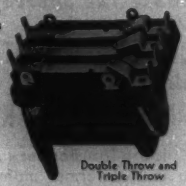

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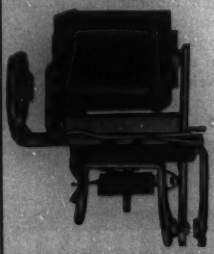

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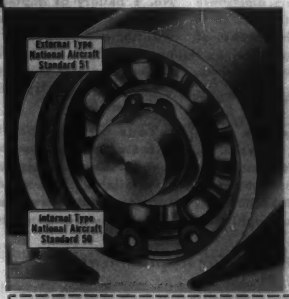

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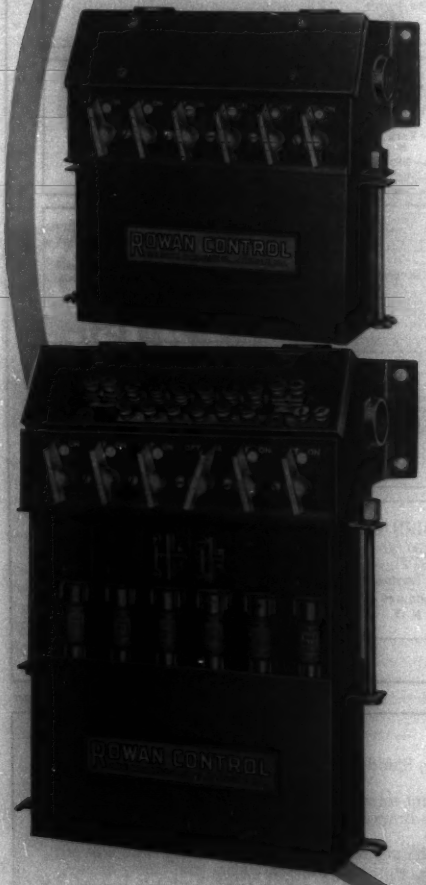
TYPE 800

LIGHTING SWITCH



Industrial demand for a rugged Lighting Switch which provides safety, dependability, minimum maintenance and positive operation for use in locations where atmospheric conditions are adverse, has been met by Rowan engineers with the new type 800, oil immersed Lighting Switch. These switches are now available in 6- and 12-gang single circuit panels of 125/250 Volt A.C., 3 wire main.

Short circuit and overload protection is provided by use of the time-tested Rowan Air-seal fuses. All electrical operating parts are completely oil immersed thereby eliminating undue heating and oxidation of the fuse clips.

Accelerated tests of over 3,000,000 operations without failure assure you of dependable performance and minimum maintenance.

Descriptive circular available upon request.

Sectional view of the Rowan time-tested Air-seal fuse.

ROWAN CONTROL

THE ROWAN CONTROLLER CO., BALTIMORE, MD.

Engineering Societies Personnel Service, Inc.

New York 8 West 40th St.
Chicago 211 West Wacker Dr.
Detroit 100 Farnsworth Ave.
San Francisco 57 Post St.

In applying for positions advertised by the Service, the applicant agrees, if actually placed in a position through the Service as a result of these advertisements, to pay a placement fee in accordance with the rates as listed by the Service. These rates have been established in order to maintain an efficient, non-profit personnel service and are available upon request. This also applies to registrants whose notices are placed in these columns.

All replies should be addressed to the key number indicated and mailed to the New York Office.

Men Available

ENGR with simplified and inexpensive electronic control for variable speed motors wants oppor to develop indus applications of same in laboratory of progressive motor or control manufacturer. E-224.

ELEC ENGR, B.S.E.E.; 26, married; exp in test, test supervision, prod and installation of motors, generators, pwr eqpt. Two yrs Army util overseas. Assoc. AIEE. E-225.

ELEC ENGR; age 30; 4 yrs mech and elec des and devpmt of polyphase induction motors, P.M. motors and transformers. Prefers northeast or middle eastern states. E-226.

ELEC ENGR; 29, married; Navy electronics; 2½ yrs Signal Corps inspection principally dynamotors and elec meters; desires prod or devpmt fields; northern New Jersey or New York City. E-227.

ELEC ENGR; B.S.E.E. (Communications) Univ. of Michigan 1945; 1 yr engr officer on steam driven ship in Navy; will go anywhere; preference sales or purchasing. E-228.

ELEC ENGR; B.S.E.E.; age 29; post grad work on Cathode Ray tubes and ultra-high radio technique; 4 yrs exper in maint of aircraft radar equipment with Navy. Desires pos in electronics devpmt, des, or research field. E-229.

Positions Available

INSTRUCTORS OR ASSISTANT PROFESSORS of electrical engineering, to teach advanced subjects in electronics and communications, or with experience in industry, to teach industrial applications of electric power and some elementary courses. Salaries, Instructors, $2100–$3000; Assistant Professors, $3000–$4000, for nine months. Location, New York, N. Y. W-6196.

ASSISTANT EDITOR, electrical engineering training, preferably with some operating experience, capable of writing and with imagination and ability to analyze the logical presentation of manuscripts. Will contact engineers during preparation of technical articles; edit and prepare for publication manuscripts, gather illustrations and supervise their preparation including proof-reading, caption writing, etc. Salary, $3600–$5000 a year. Location, Pennsylvania. W-7258.

RESEARCH ENGINEERS. (a) Research Engineer, 28–35, graduate, with about five years' experience in the field of audio and video electronics. Familiarity with telephone communications, audio-filter designing and beam broadcasting essential. Salary, $4800–$5400 a year. Location, northern New Jersey. (b) Research Engineer, 30–35, graduate electrical or physics, with minimum of ten years' experience in audio and video electronics. Would like knowledge of audio wave filter design, FM theory and circuit application. Salary open. Location, New York, N. Y. W-7291.

INSTRUCTOR, 22–30, electrical graduate, to teach electrical engineering. Industrial or teaching experience desirable but not essential. Position starts September 1, 1946. Salary, about $2400 for ten months. Location, upstate New York. W-7292.

INSTRUCTORS. (a) Instructor or Assistant Professor of electrical engineering, to teach class room and laboratory courses in electrical engineering. Salary, $2800–$3800 for ten months. (b) Instructor or Assistant Professor of engineering or management. Duties involve part-time teaching and part-time personnel work. Teaching including such courses as engineering economics, engineering law and industrial engineering. Personnel work involves guidance of pre-engineering students, placement and public relations work. Positions start September 1946. Location, New Hampshire. W-7294.

ACOUSTIC PHYSICIST for research and development in supersonic field. Ability to design electro-acoustic systems, including measurement of acoustic properties of materials required. Salary commensurate with ability. Location, New England. W-7306.

DEVELOPMENT ENGINEER, to 45, electrical engineering graduate or equivalent, with considerable experience, to develop engineering project in the field of fluorescent and neon lighting, etc., involving design and requirements of transformers and reactors, etc.; devise tests and improvise testing equipment as required, etc. Salary, $4420 a year. Location, Connecticut. W-7315.

PHYSICIST, young, to head up physical laboratory dealing with properties of plastics, cemented plastics, engineering and physical data on plastics. Would have to conduct experiments, write up reports and carry on certain research. Salary, about $5000 a year. Location, New York, N. Y. W-7325(b).

INSTRUCTORS OR ASSOCIATE PROFESSORS of electrical engineering, electronics, high frequency and electrical machinery. Salary, $2000–$3600 for nine months. Rank and salary depending upon experience. Location, Texas. W-7324.

ENGINEERS for the following fields: (a) Electronics, especially need a group leader. Should be mature in scientific judgment and able to furnish good research leadership; (b) Electrical engineering, particularly for research in laboratory. Location, Pennsylvania. W-7325.

CHIEF ENGINEER AND MANAGER having experience in the manufacture of both dry cells and layer built batteries. Should have ability to train local personnel and be able to get along with workmen. Three-year contract. Location, India. W-7342.

ACOUSTICAL ENGINEER, graduate, preferably physics or electrical engineering, with two to five years' experience in acoustical work or development of electronic or other instruments for acoustical applications or other electro-mechanical work, for development and application of electronic equipment for the measurement, analysis and synthesis of aircraft noise and preparation of reports on noise characteristics of aircraft. Salary, about $3600 a year. Location, Connecticut. W-7347(a).

ELECTRICAL ENGINEER well versed in electronic principles, to work on new developments for manufacturer of instruments and control devices. Write attaching small photograph. Location, Connecticut. W-7351.

ELECTRICAL ENGINEER with at least ten years' experience in the design of electrical generating and distribution equipment and systems, design of communication and navigation equipment, etc., preferably in airports or industrial buildings. Will be required to assist in drafting and preparation of specifications and bills of materials. Salary open. Location, northern New Jersey. W-7369 (a).

INSTRUCTOR of technical electricity, electrical graduate, with at least three years' experience in the electrical field, preferably with electric motor control. Experience in electric power or laboratory work will be considered. Salary, $2250 a year, plus 22% cost of living bonus. Location, upstate New York. W-7386(b).

ASSISTANT PLANT ENGINEER, electrical graduate, with at least five years' experience in laying out generation and distribution facilities in industrial or metallurgical plant. Salary, $3600–$4800 a year. Location, Westchester County, New York. W-7398.

RADIO DEVELOPMENT ENGINEER with experience in frequency modulation and having the ability to take charge of original developments in FM and ultra-high frequencies. Permanent. Salary, approximately $4200 a year. Location, south Midwest. W-7402.

CLASSIFIED ADVERTISEMENTS

RATES: Sixty cents per line; minimum charge based on use of five lines; maximum space not to exceed thirty-five lines. Copy is due on the 18th of the month preceding publication date.

WANTED—ELECTRICAL ENGINEER—for power plant design, must have public utility experience. WESTCOTT & MAPES, Inc., New Haven, Connecticut.

ILLUMINATING ENGINEER, experienced in commercial, industrial and power plant lighting and circuit design, capable of creative work in obtaining dynamic lighting effects. Location—Boston. Address Box 379, Electrical Engineering, 33 West 39th Street, New York 18, N. Y.

EXECUTIVE ENGINEER—Age 40, married; Engineering graduate; 19 years diversified electrical and mechanical experience in 3 outstanding companies, heavy-industrial, gas and electric, utility and precision, electro-mechanical and electronic manufacturer in eng., application and sales. Now employed in administrative engineering position. Desire administrative or executive position with established, progressive company, utilizing broad engineering background. Responsible, adaptable, cooperative, good personality and appearance. Prefer east or west coast. Salary $8,000 or equivalent with incentives. Address Box 380, Electrical Engineering, 33 West 39th Street, New York 18, N. Y.

GRADUATE ELECTRICAL ENGINEER with ten years experience in development, research, design, tooling and production in medium and large size electrical machinery. Would like position in development or research. Address, Box 381, Electrical Engineering, 33 West 39th Street, New York 18, N. Y.

ELECTRICAL ENGINEER, 1943 graduate, 25 years old, married, 2 children. Completed General Electric Test Course. Fluent Spanish. Desire position New York City area or South America. Available immediately. Address Box 383, Electrical Engineering, 33 West 39th Street, New York 18, N. Y.

WANTED

The Tennessee Valley Authority has vacancies for electrical laboratory technicians in its Electrical Laboratory and Test Division located in Chattanooga, Tennessee.

These positions are classified as Electrical Engineer I with an entrance salary of $2770 based on a 40-hour work week schedule with opportunity for within-grade increases and promotion.

Candidates must have experience in the repair and calibration of delicate electrical instruments including a thorough knowledge of electrical measurements.

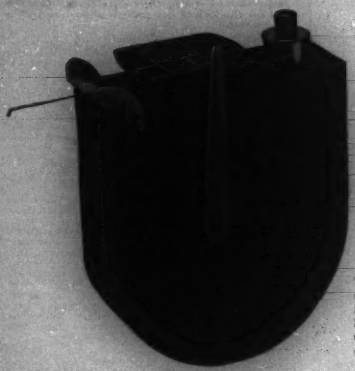
Interested persons should write the

Personnel Department

TENNESSEE VALLEY AUTHORITY

Chattanooga Tennessee

Brush Magnetic Oscillographs



make direct-writing recordings from D. C. to 100 cycles per second!

The remarkable new Brush Magnetic Recording Pen Motor—heart of the Brush Direct-Inking Oscillograph. Highly stable. May be used under virtually any climatic or temperature conditions. Exceptional accuracy.

● *Instantaneous, permanent,* ink-on-paper recordings by Brush Oscillographs make their use almost unlimited. Accurate recordings of strains, pressures and countless electrical phenomena can be made over a frequency range of *D.C. to 100* c.p.s. Either A.C. or D.C. circuits can be measured. Whenever desired, recordings may be stopped for notations on chart-paper.

Brush Oscillographs are compact, portable and ruggedly constructed for ease of handling and operation. Investigate them now. Brush engineers will gladly co-operate in determining their application to your problems. Write for technical bulletin No. 593 for complete details of this equipment.

Brush Single-Channel Magnetic Oscillograph with amplifier. Especially suited for counting, temperature recording, surface analysis—and similar applications. Three-speed paper drive, 5, 25, 125 mm per second. Chart paper 2⅜" wide.

Brush Double-Channel Magnetic Oscillograph for use where two simultaneous recordings are desired—as in synchronizing problems. Three-speed paper drive, 5, 25, 125 mm per second. Chart paper 3⅛₂" wide.

Brush Six-Channel Magnetic Oscillograph. Excellent for strain-gauge recordings. Dust-proof case. Interchangeable gear paper drive. Your choice of paper speeds from ⅛" to 5" per second. Chart paper 12" wide.

THE BRUSH DEVELOPMENT CO.

3405 PERKINS AVENUE • CLEVELAND 14, OHIO

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For SOUTHWARK STATION'S Generator Leads ...I-T-E ISOLATED PHASE BUS

Our role in the construction of Philadelphia Electric's Southwark Station—the last word in power generation equipment—is in the form of I-T-E Isolated Phase Bus for the generator leads—both main (13.8 kv, 5000 amp.) and auxiliary (4160 v, 2200 amp.).

The use of Isolated Phase Bus assures reliable and efficient operation, with maximum separation of phases and minimum opportunity for trouble between phases. Its construction is ideal for use in constricted space areas, as well as those places which normally are considered unsafe for the location of high voltage conductors.

Other advantages inherent in these structures are: cleanliness insured by easily aligned, dust-tight metal housings . . . elimination of all but compression stress in the porcelain insulators . . . silver-surfaced bus joints, preventing increase in resistance with oxidation . . . low conductor reactance . . . greater safety . . . low cost installation.

For more complete information, send for Bulletin 4604, describing an isolated phase bus installation in an Eastern central station, I-T-E Circuit Breaker Company, 19th and Hamilton Streets, Philadelphia 30, Pa.

View of 2200 ampere, 4160 volt auxiliary generator leads as they rise 90 feet above the generator floor.

A section of the 5000 ampere, 13.8 kv main generator leads with individual phase enclosures not yet in position.

HIGH SPEED CIRCUIT BREAKERS • SWITCHGEAR
BUS STRUCTURES • SUBSTATION UNITS
AUTOMATIC RECLOSING CIRCUIT BREAKERS

I-T-E ISOLATED PHASE BUS STRUCTURES

Heres Why

G-E AUTOMATIC VOLTAGE STABILIZERS

Safeguard your Equipment

- ✓ **Less than ± 1% variation on all applications!**
- ✓ **Practically instantaneous voltage correction!**
- ✓ **No moving parts; no adjustments!**
- ✓ **Will operate continuously at open or short circuit without excessive damage!**

This General Electric voltage stabilizer is excellent for use where it is necessary to keep a-c output voltage right where it belongs. It provides a constant, precise output of 115 volts from any a-c source that may vary from 95 to 130 volts.

The G-E voltage stabilizer protects costly laboratory and other equipment from sudden over-voltages, speeds production line testing. It gives longer life to testing apparatus, radio transmitting tubes, x-ray filament circuits, motion-picture equipment. Here are some of its more outstanding characteristics which qualify it as a precision voltage stabilizer:

- *Maintains voltage regulation* for fixed loads to within ±1 per cent. Maintains regulation to within 2 per cent on heavy variations occurring between no load and full load.
- *Automatic action* eliminates moving parts, adjustments, etc.
- *Instantaneous action* provides voltage correction in less than three cycles time.
- *Limits current* at short circuit to approximately 180 per cent of full load.
- *Low harmonic content*, negligible variation over wide load range.

For complete details on this stabilizer's unusual possibilities, write for Bulletin GEA-3634, *Apparatus Dept., General Electric Company, Schenectady 5, N. Y.*

Turn the Knob and Set the Voltage

For giving the right voltage when you want it, this variable-voltage autotransformer is an asset to any laboratory or shop bench. By merely turning the control knob, you can have any voltage from zero to 135 volts from a 115-volt a-c input, zero to 270 volts on a 220-volt a-c input. For complete description, ask for Bulletin GEA-3635A.

GENERAL ELECTRIC